PB 184576

A COST ANALYSIS OF AIR-POLLUTION CONTROLS IN THE INTEGRATED IRON AND STEEL INDUSTRY

Contract No. PH 22-68-65

to

DIVISION OF ECONOMIC EFFECTS RESEARCH
NATIONAL AIR POLLUTION CONTROL
ADMINISTRATION
DEPARTMENT OF HEALTH, EDUCATION,
AND WELFARE

May 15, 1969

(Complementary Final Technological
Report is also dated May 15, 1969.)

BATTELLE MEMORIAL INSTITUTE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Reproduced by the
CLEARINGHOUSE
for Federal Scientific & Technical
Information Springfield Va. 22151

259

A COST ANALYSIS OF AIR-POLLUTION CONTROLS IN THE INTEGRATED IRON AND STEEL INDUSTRY

(Contract No. PH 22-68-65)

to

DIVISION OF ECONOMIC EFFECTS RESEARCH
NATIONAL AIR POLLUTION CONTROL ADMINISTRATION
DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

May 15, 1969

by

Thomas M. Barnes; Principal Investigator
H. W. Lownie, Jr.; Project Director

BATTELLE MEMORIAL INSTITUTE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Battelle Memorial Institute · COLUMBUS LABORATORIES

505 KING AVENUE COLUMBUS, OHIO 43201 · AREA CODE 614, TELEPHONE 299-3151 · CABLE ADDRESS: BATMIN

May 29, 1969

Mr. Norman Plaks
Division of Process Control Engineering
National Air Pollution Control
Administration
5710 Wooster Pike
Cincinnati, Ohio 45527

Dr. Paul Kenline
Division of Economic Effects Research
National Air Pollution Control
Administration
1055 Laidlaw Avenue
Cincinnati, Ohio 45237

Mr. N. G. Edmisten
Division of Economic Effects Research
National Air Pollution Control
Administration
411 W. Chapel Hill Street
Durham, North Carolina 27701

Gentlemen:

A Cost Analysis of Air-Pollution Controls
in the Integrated Iron and
Steel Industry
(Contract No. PH 22-68-65)

Two copies of the subject report are being sent to both Mr. Plaks and Mr. Edmisten, and 96 copies to Dr. Kenline.

For the companion Final Technological Report, two copies are being sent to both Mr. Edmisten and Dr. Kenline, and 96 copies to Mr. Plaks.

Very truly yours,

H W Lownie Jr.

H. W. Lownie, Jr.
Project Director

HWL:jls

TABLE OF CONTENTS

Page

SECTION I

INTRODUCTION I-1

SCOPE AND OBJECTIVES OF THE PHASE I STUDIES I-1

ORGANIZATION AND CONTENTS OF THIS REPORT I-3

SECTION II

SUMMARY II-1

Section III: A Profile of the American Steel Industry II-2
Industry Resources for Growth and Change II-2
Distribution of Costs in a Hypothetical Steelworks II-3
Section IV: The Technical Determinants of Air-Pollution Control Cost II-4
Priorities, Problems, and Opportunities in Pollution-Control Technology II-5
Section V: Specific Cost/Effectiveness Investigations II-6
Methodology II-6
Results and Analysis II-6
Section VI: Findings and Recommendations II-7

SECTION III

A PROFILE OF THE AMERICAN STEEL INDUSTRY III-1

INDUSTRY RESOURCES FOR GROWTH AND CHANGE III-6

Operating Margins III-7
Cash Generation III-7
Return on Equity III-10
Indebtedness III-10
New Capital Spending III-10
Overview III-13

DISTRIBUTION OF COSTS IN A HYPOTHETICAL STEELWORKS III-14

Introduction III-14
Costs: Raw Materials III-14
Costs Above Raw Materials III-17
Total Annual Costs and Revenues III-17

REFERENCES III-24

TABLE OF CONTENTS
(Continued)

Page

SECTION IV

THE TECHNICAL DETERMINANTS OF AIR-POLLUTION CONTROL COST . . IV-1

Receipt, Storage, and Handling of Raw Materials IV-1
Coking IV-2
    Charging and Coking IV-2
    Pushing IV-5
    Coke Quenching IV-5
    Coke Handling IV-5
    By-Product Processing IV-5
Preprocessing Raw Materials IV-6
    Sintering IV-6
    Pelletizing IV-6
Ironmaking IV-8
    Charging IV-8
    Smelting IV-10
    Casting and Flushing IV-10
Steelmaking IV-11
    Open-Hearth Furnaces IV-11
    Basic Oxygen Furnaces IV-14
    Electric-Arc Furnaces IV-14
    Vacuum Degassing of Steel IV-19
    Continuous Casting of Steel IV-19
Steel Shaping IV-19
    Primary Breakdown IV-19
    Conditioning, Reheating, and Hot Rolling IV-23
    Acid Pickling IV-23
    Cold Rolling and Cold Forming IV-23
Steel Finishing IV-24
Miscellaneous Operations IV-24
    Gas Distribution IV-24
    Powerhouse IV-25
    Plant Waste Incineration IV-25
Priorities, Problems, and Opportunities in Pollution-Control Technology IV-26
    Priorities IV-26
    Problems IV-27
    Opportunities IV-28

SECTION V

SPECIFIC COST/EFFECTIVENESS INVESTIGATIONS V-1

METHODOLOGY V-3

TABLE OF CONTENTS
(Continued)

Page

Engineering Estimates V-3
Definition of the Form of the Model V-4
    Modeling, Pretesting, and Interpretation V-10

RESULTS AND ANALYSIS V-14

Coke-Oven Charging V-14
Coke-Oven End-Door Seals V-14
Coke-Oven Pushing V-15
Quenching of Coke V-15
By-Product Processing V-15
Coke-Oven Gas Systems V-15
Ore and Flux Handling V-16
Sintering V-16
Pelletizing V-18
Blast-Furnace Charging V-18
Ironmaking Slag Disposal V-19
Steelmaking V-19
    Electric-Arc Steelmaking V-19
    Basic Oxygen Steelmaking V-21
    Open-Hearth Steelmaking V-23
    Steelmaking: Overview V-23
Teeming of Molten Steel V-25
Slab and Billet Conditioning V-25
Hot-Rolling and Hot-Working of Steel V-26

SECTION VI

FINDINGS AND RECOMMENDATIONS VI-1

Criteria for Planning Future Phases VI-2
Organization and Objectives of Phases II, III, and IV . . . VI-3
Phase II: Study of Process Segments Now Largely Controlled . . VI-4
    Assembly of Data VI-4
    Data Processing VI-6
    Application of Cost Models VI-6
Phases III and IV: Study of Other Process Segments VI-7

APPENDIXES

A. LIST OF STEELWORKS BY TYPES A-1

B. EXAMPLE SUMMARY SHEETS B-1

C. COSTS AND PERFORMANCE OF CONTROL SYSTEMS AND CONTROL EQUIPMENT C-1

LIST OF FIGURES

Page

Figure III-1. Geographic Distribution of Raw Steel Production in the United States in 1967 . . . . III-2

Figure III-2. Distribution of Steel Sales Among U. S. Companies, 1967 . . . . III-4

Figure III-3. Raw Steel Production and Finished Steel Shipments, 1958-67 . . III-5

Figure III-4. Operating Margins in the U. S. Steel Industry, 1958-67 . . . III-8

Figure III-5. Cash Flows Generated by the U. S. Steel Industry, 1958-67 . . III-9

Figure III-6. Returns on Equity Investment in the U. S. Steel Industry . . . III-11

Figure III-7. Ratio of Long-Term Debt to Total Assets in the U. S. Steel Industry, 1958-67 . . . . III-12

Figure III-8. Flow Chart for 1,693,000 Net Tons of Products Per Year for Hypothetical Steel Corporation's Plant in Ohio III-15

Figure IV-1. Typical Flow Sheet for a By-Product Coke Plant IV-3

Figure IV-2. By-Product Plant Flowsheet IV-4

Figure IV-3. Typical Flow Sheet for a Sintering Plant IV-7

Figure IV-4. Typical Blast-Furnace Operation With a Burden Consisting Mainly of Sinter, and With Injection of Natural Gas IV-9

Figure IV-5. Open-Hearth Furnace Operating With Hot-Metal Practice Consisting of 60 Percent Hot Metal and 40 Percent Steel Scrap (Ore Practice) IV-12

Figure IV-6. Illustrative Flow Diagrams of Open-Hearth Dust-Collecting Systems IV-13

Figure IV-7. Basic Oxygen Furnace Operating With 70 Percent Hot Metal and 30 Percent Steel Scrap IV-15

Figure IV-8. Examples of Gas-Cleaning Systems for BOF Steelmaking Furnaces IV-16

Figure IV-9. Example of Electric-Furnace Steelmaking Practice IV-18

Figure IV-10. Examples of Electric-Furnace Direct-Extraction Emission-Control Systems With Baghouses IV-20

LIST OF FIGURES
(Continued)

Page

Figure IV-11. Examples of Electric-Furnace Dust-Collecting Systems Using Wet Scrubbers IV-21

Figure IV-12. Examples of Electric-Furnace Shop-Roof Emission-Control Systems IV-22

Figure V-1. General View of a Curved Surface in Cartesian Space V-8

LIST OF TABLES

Table I-1. The Principal Operations of the Integrated Iron and Steel Industry I-2

Table I-2. Economic Studies and Researches Included in Phase I Studies of the Integrated Iron and Steel Industry I-4

Table III-1. Annual Capital Spending as a Percentage of Fixed Assets . . . III-13

Table III-2. Prices and Amounts of Major Items Consumed in the Hypothetical Steel Corporation's Ohio Plant III-16

Table III-3. Estimated Operating Cost for Making Hot Metal in Hypothetical Steel Corporation's Ohio Blast Furnace at a Rate of 1,200,000 Net Tons Per Year III-18

Table III-4. Estimated Operating Costs for Steelmaking in a BOF Shop With an Annual Capacity of 1,500,000 Net Tons of Molten Steel III-19

Table III-5. Estimated Operating Costs for Steelmaking in an Electric Furnace Shop With an Annual Capacity of 500,000 Net Tons of Molten Steel III-19

Table III-6. Estimated Operating Cost for Continuous Casting of 1,440,000 Net Tons of Slabs and 480,000 Net Tons of Billets III-20

Table III-7. Estimated Operating Cost for Making 167,400 Net Tons of Wire Rod and 270,000 Net Tons of Merchant Bar From Continuously Cast Billets III-21

Table III-8. Estimated Operating Cost for Hot-Rolled Coils and Sheets. . . III-21

Table III-9. Estimated Operating Cost for Cold-Rolled Coils and Sheet. . . III-22

LIST OF TABLES
(Continued)

		Page
Table III-10.	Summary of Estimated Costs and Revenues for Hypothetical Steel Corporation's Ohio Plant	III-23
Table V-1.	Air-Pollution Control Problems Considered in Phase I Studies	V-11
Table V-2.	Data, Modeling Results, and Pretests for Sintering Plants . .	V-17
Table V-3.	Data and Modeling Results for Pelletizing Plants	V-18
Table V-4.	Data, Modeling Results, and Pretests for Electric-Arc Furnaces	V-20
Table V-5.	Data, Modeling Results, and Pretests for Basix Oxygen Furnaces	V-22
Table V-6.	Data, Modeling Results, and Pretests for Open-Hearth Furnaces	V-24
Table V-7.	Data and Modeling Results for Scarfing Machines.	V-26
Table VI-1.	Process Segments of the Integrated Iron and Steel Industry, Categorized According to the State of Progress in Air-Pollution Control	VI-2

SECTION I

INTRODUCTION

The National Air Pollution Control Administration (NAPCA) is an agency of the U. S. Department of Health, Education and Welfare. As such, it is charged with certain research responsibilities under the terms of the Air Quality Act of 1967 (Public Law 90-148). In fulfilling these responsibilities, NAPCA is sponsoring analytical studies of air-pollution control in selected industries.

When completed, the industrial studies will describe

(1) The present status of air-pollution control technology

(2) The cost of controlling air-polluting emissions

(3) The needs for research and development toward better controls.

An important feature of the industrial studies is that the companies within each studied industry have been requested by NAPCA to participate directly. It is recognized that joint efforts, with data and guidance supplied by the industries themselves, will best assure that the studies are responsive and authoritative.

NAPCA plans to use the results of the industry studies, together with information about other air-pollution sources, to project both regional and national summaries of the status and cost of air-pollution control. The projections will be used to assess the cost effects of proposed or changing air-quality standards. At the same time, the technical problems and priorities identified during the studies will be used to help plan and direct appropriate research and development programs.

In accord with the overall objectives, this analytical study of the integrated iron and steel industry was jointly sponsored by two divisions of NAPCA. This is an economic (cost) report prepared for the Division of Economic Effects Research which is responsible for determining the economic impact of air-quality standards upon industries and other sources of air pollution. The other sponsoring group, which receives a complementary technical report, is the Division of Process Control Engineering, which is responsible for technical aspects of Federally sponsored research and development on the control of air pollution from stationary sources.

SCOPE AND OBJECTIVES OF THE PHASE I STUDIES

The integrated iron and steel industry, defined for present purposes by the generalized list of operations in Table I-1, was selected for analysis because a number of its key processes can contribute to air pollution. Within the steel industry, there are many challenging, often unique, technical problems in controlling or preventing emissions. Metallurgical fumes are characteristically finer in particle size, higher in opacity, and otherwise more complex than other process emissions such as those from power generation.

The economic cost analysis and planning of controls is also quite complex, mainly because of delicate competitive balances between process alternatives. Because the steel industry is made up of physically large components, capital decisions inevitably commit large sums of money; considerations of money already invested tend to retard change in some instances.

TABLE I-1. THE PRINCIPAL OPERATIONS OF THE INTEGRATED IRON AND STEEL INDUSTRY

I.	Receipt, storage, and handling of raw materials
II.	Coking of coals and recovery of coal chemicals
III.	Pre-treatment of iron-bearing materials by agglomeration
IV.	Smelting of iron ores with coke to produce iron
V.	Conversion of iron into steel, and remelting of scrap
VI.	Processing of raw steel into saleable shapes
VII.	Finishing of steels; especially surface treatment
VIII.	Ancillary operations, e.g., steam and power generation

Note: Some Definitions Pertinent to Steel-Industry Studies

Integrated Steelworks: A plant or group of adjacent plants which conducts a number of the above operations including at least IV, V, and VI. Tonnagewise, most steel is produced in these.

Secondary Steelworks: A plant which conducts Operations V and VI (at least), but which does not conduct Operations II, III, and IV. Numerically, most steelworks are of this type.

Steel Processing Plant: A plant which obtains raw or semifinished steel from other plants and emphasizes Operations VI and/or VII.

Ironworks: A plant based on Operations I to IV; producer of pig iron, ferromanganese, or other ferrous alloys.

Coke Plant: A plant based on Operation II, and which produces no iron or steel.

This study is identified as Phase I of a series. It has the specific purpose of

(1) Analyzing present costs for air-pollution control, and determining procedures for estimating total costs for controlling to such standards of air quality as may become established, and

(2) Defining problem areas and needs, thereby providing one basis for establishing priorities for federally sponsored research and development projects.

Purpose (1) corresponds to the goals of this project for the Division of Economic Effects Research, and has been emphasized in this cost report. Table I-2 lists the work of the Phase I cost studies in general terms.

ORGANIZATION AND CONTENTS OF THIS REPORT

In preparing a separate final report for each of the two sponsoring divisions of NAPCA, it has been intended that each shall be a self-sufficient document oriented to divisional purposes and needs. Accordingly, background technical information has been included in this economic report, and background economic information has been similarly incorporated into the technical report.

Section I is this introduction to the project and to the economic report; it is prepared to orient readers inside and outside of NAPCA to NAPCA's overall purposes as they are expressed in this project. The tables in Section I define the area of study and describe the research that was performed.

Section II is a summary of significant results obtained from the Phase I cost/effectiveness studies. It contains commentary on the evolution of steelmaking macroeconomics as affecting the industry's ability to support new air-pollution control activities. It reviews the areas of interaction between control costs and control technology and underscores problems and marginal situations where an adequate response to the Air Quality Act of 1967 must depend upon technical progress. The summary section also presents the overall findings from the development of models and methodology for comprehensive analysis. Throughout Section II, the emphasis is upon implications for the continuation of the research.

Section III is a three-part presentation of the business economics of steelmaking, and includes geographic and organizational profiles of the industry, a 10-year business profile with emphasis on cash generated and returns obtained, and a presentation of the approximate distribution of costs within a hypothetical Ohio steelworks. The purpose of Section III is to orient economic analysis to the nature of the steel industry, its economic size and strength, and its internal cost structures. Together, the presentations of Section III form a body of necessary background to the more comprehensive analysis planned for the future.

Section IV is a compilation of technical background information derived from interim reports and the complementary final technological report. Section IV has two purposes: one is to introduce the elements of steelmaking which are considered to be sources of air pollution (and therefore objects of economic study), and the other is to point out subjects of technical difficulty or inordinate control cost where permanent solutions are still to be attained. The section concludes with an overall statement of the steel industry's air-pollution priorities and problems, categorized according to their relative basis in technology or economics. This analytical statement includes some preliminary opinions about the likelihood of attaining solutions through applied research.

TABLE I-2. ECONOMIC STUDIES AND RESEARCHES INCLUDED IN PHASE I STUDIES OF THE INTEGRATED IRON AND STEEL INDUSTRY

I. The integrated iron and steel industry was segmented and subsegmented into processes and operations suited to the selective analysis of air-pollution problems and controls. This segmentation is presented in Table V-1.

II. Data were compiled from the literature, from industry sources both by direct visit and by special solicitation, from the suppliers of control apparatus, and from state governments. These data were augmented by engineering estimates of control costs prepared by the Swindell-Dressler Company[a] from information in their own files or procured by them.

III. Statistics characterizing the steel industry, as prepared by the American Iron and Steel Institute and others, were studied and analyzed to obtain suitable economic profiles and projections as a background for future studies and as a basis for the interpretation of Phase I data.

IV. An expression for use in the modeling of control costs was devised as an analytical tool in compiling and adjusting estimates of regional or national control costs on a process-by-process basis.

V. By reference to all data available from all sources, the proposed model expression was pre-tested and evaluated as applied to fifteen representative steelworks operations.

VI. The relative usefulness of the various data-gathering, data-generation, and data-reduction techniques was critically reviewed and evaluated as a prelude to subsequent study.

(a) Swindell-Dressler Company was a subcontractor to Battelle for some aspects of this Phase I study.

Section V is the heart of this report. It presents the results of the specific analyses performed in this project. The first part of Section V describes the purposes and methods of the cost studies, and the second part gives the results for 15 specific studies of representative steelmaking operations. For each operation studied, data drawn from non-industry sources or estimated by the study subcontractor, Swindell-Dressler, were modeled and compared with data obtained directly from within the steel industry. The results of mathematical modeling and pretesting of the models are given in all instances where data were sufficient to permit a meaningful test. Most results of the special cost studies performed by Swindell-Dressler were incorporated into the specific case studies of Section V.

Section VI presents Battelle's findings and recommendations and focuses upon the experiences gained in obtaining, reducing, and analyzing data that characterize the cost of air-pollution controls in steel plants. Section VI assesses the future application of methods and models developed in Phase I, and describes the main limitations to be observed as the studies are continued into characterization of other process segments and broader representations of the steel industry.

BLANK PAGE

SECTION II

SUMMARY

The overall objectives of this study of the steel industry ~~are~~ was to determine:

(1) The present status of air-pollution control technology

(2) The cost of applying present technology to the lessening of air pollution by steelworks

(3) The subjects on which research and development are needed to improve the technology and economics of air-pollution control.

The study was conducted in 1968 and early 1969 by Battelle Memorial Institute, Columbus Laboratories, with substantial subcontracted assistance from Swindell-Dressler Company of Pittsburgh and voluntary assistance from a number of steel companies that contributed information and guidance throughout the project.

This Final Economic Report is complete in this volume. It includes the report proper, plus Appendixes A and B, and Appendix C is the final report of the Swindell-Dressler Company. A complementary volume is entitled "Final Technological Report on a Systems Analysis Study of the Integrated Iron and Steel Industry".

The partition of the final Battelle reports reflects the design of this study to serve both the Division of Economic Effects Research and the Division of Process Control Engineering of the National Air Pollution Control Administration.

In the economic (cost) aspects of the study, Battelle and Swindell-Dressler had the following general objectives:

(1) To develop background depicting the economic position of the American steel industry, as a basis for study of the costs of controlling air pollution

(2) To develop technical background indicative of the general problems and priorities of steelworks air-quality endeavors

(3) To prepare for specific and comprehensive cost analyses by developing methods for obtaining and analyzing data representative of the present and future costs of controlling steelworks emissions to any given standard of effectiveness.

The third objective was emphasized. As Phase I of an expected series, this cost-analysis study was to prepare for and lead into more detailed phases.

This report contains four sections other than the Introduction and this Summary. Three of them (Sections III, IV, and V) deal topically with the above general objectives. The last (Section VI) offers Battelle's recommendations to NAPCA for the continuation of economic studies into Phase II and beyond. The following paragraphs summarize the findings and recommendations from each of the main sections of this report.

Section III: A Profile of the American Steel Industry

The United States continues as the world's largest steelmaker, despite recent inroads made by imported steel from Japan and Western Europe. Steelmaking is practiced in many states (even Hawaii), but is heavily concentrated in the northeast central belt of states from Illinois east to Pennsylvania. There are two principal types of steel plants: integrated plants and secondary plants. Integrated plants manufacture iron from its oxide ore, then convert the iron to steel in a separate operation. Secondary steelworks smelt no ore, but produce steel by remelting scrap steel and repeating the refining steps. In addition to the 49 primary (integrated) and 100 or more secondary steelworks, the United States has a number of plants that perform smaller segments of the steelmaking job. These include coke plants, ironworks, and steel rolling and finishing plants. At the present time, high capital costs for construction of all-new integrated steel plants, together with very favorable trends in the cost of scrap, have encouraged construction of new secondary steelworks. However, the major share of postwar growth in overall steelmaking capacity has occurred through modernization and expansion of existing integrated plants.

The economy of scale inherent in integrated steelmaking, and the advantages of vertically integrating operations from mines to warehouses, have led to the formation of some very large enterprises comparable to the big automakers and the larger oil companies. But economies of distribution (especially for low-priced products such as concrete-reinforcing bar, or for very specialized products such as tool steels) have also led to the formation of some small enterprises on a profitable basis. The larger mills are vulnerable to the ills of mass production. To fill modest orders, they must maintain large inventories which incur costs that erode the natural advantages of high-volume production. Little steelmakers operate close to their markets in every sense of the word, and compete vigorously and successfully with large integrated steel companies.

Industry Resources for Growth and Change

Financially, the steel industry (as a whole) has some problems. In a labor market of constantly increasing cost per man-hour, steelmakers have spent large amounts of capital to mechanize and automate operations, or to make them more productive. The costs of purchased materials and services have gone up steadily, and have not been offset in full by rising prices. The paid-in revenue per ton of finished steel shipped has in fact remained almost constant from 1958 to 1967. Operating margins have narrowed generally, and have become extremely erratic since 1963. This, combined with rising fixed charges for the new equipment, has squeezed profits to a level well below the level typical for durables manufacturing. More and more of the cash flows generated by steelmakers have been in the form of depreciation, depletion, and amortization allowances.

Low return on investors' equity, together with the erratic behavior of steel earnings (intensified by the growing load of fixed charges), has made it difficult for the steelmakers to issue securities on favorable terms. The indebtedness of steelmakers has grown substantially, and there have been a number of mergers, absorptions, and other upheavals in recent years. In 1969, an investor can still buy some steel stocks well below their book values.

Since 1960, capital spending by steelmakers, especially for modernization, has taken a sharp upturn. It now exceeds 20 percent of fixed assets annually. If these capital expenditures yield the expected results, steelmakers may attain a turnaround in their fiscal performance and regain some equilibrium. Otherwise, the general squeezes and the erratic effects of leverage might continue or intensify. The biggest concern of all is that imports will prevent full utilization of new and modernized facilities.

Distribution of Costs in a Hypothetical Steelworks

Hypothetical Steel Corporation, founded by Battelle (for the purposes of this study) on the shores of Lake Erie, in Ohio, produces steel for the sole purpose of illustrating where the steelmaking dollar is spent. The following tabulation summarizes this information:

Item	Cost per Year	Cost per Shipped Net Ton
Iron ore, coal, limestone, and finishing additions	$40,835,536	$24.10
Purchased steel scrap	20,000,466	11.80
Other materials and fuels	11,090,250	6.60
Labor, utilities, refractories, purchased services, and other conversion costs	55,490,124	32.80
Sales and administration expense	11,057,400	6.20
Fixed charges on capital	72,000,000	42.50
Total	$210,473,776	$124.00

The profitability of Hypothetical Steel Corporation is only 4 percent on sales (before taxes), and 1.8 percent (pretax) on investment. This is a result of high fixed charges in the new plant. An older plant of the same type might incur only about $60 million in fixed charges, and profits would be more than double those cited.

Section IV: The Technical Determinants of Air-Pollution Control Cost

Both particulate matter and undesirable gases are generated in the operations of steel manufacture. Nearly all plant activities (except the actual generation of electricity from steam) give rise to some form of air pollution.

Depending on the weather and the dryness of raw materials, the release of particulate dirt at hundreds of transfer points may be one of the biggest problems in a steel plant. Immense amounts of ore, coal, limestone, and intermediates made from these raw materials are unloaded, stocked, reclaimed, batched, blended, crushed, screened, charged to processes, and otherwise handled on a round-the-clock basis. At each point where the materials are in motion or exposed to drafts, a wisp of dust may arise – trivial in itself, but contributing to a severe overall effect. Control over this system is exercised by wetting, shrouding, exhausting through dust collectors, and numerous other means; but existing materials-handling arrangements are often difficult to reshape for modern dust-control standards. A particularly difficult problem arises in the charging of coke ovens because the coal releases both dust and fumes.

Particulates also are released in the internal operations of smelting iron ore and converting the resulting iron to steel. Ores abrade as they descend in the stack of the blast furnace, and the resultant dusts are carefully collected for recycling. But the sintering operation required to re-agglomerate the dusts (and to utilize the finer ores) is a center of dust raising. Sintering requires forced drafts, both for formation and for cooling of the sinter, and the task of cleaning sintering exhausts is a major one. As molten iron emerges from the blast furnace, it begins almost immediately to release airborne graphite called kish. This kish forms and escapes continually whenever the blast-furnace iron is handled in a molten state. In steelmaking, dust and dirt from scrap is compounded with fumes from the oxidizing reactions that convert blast-furnace iron to steel. Modern practices based on accelerating these reactions with injected oxygen can generate a plume of red iron-oxide dust visible for many miles. The steel companies have taken particular pains to contain, collect, and either process or dispose of the dusts generated in blast furnaces, sinter plants, and steelmaking furnaces.

Other releases of particulates occur in the operations of quenching incandescent coke, in the conditioning of slabs and billets with jets of oxygen, and in the high-speed operations of the final stages of hot rolling. For all such instances, controls have been established wherever the configuration of existing equipment facilitates a reasonably practical approach. The oldest air-pollution controls are applied to cleaning blast-furnace gas, which has value as cleaned. Newer control devices, at ever-higher cost per unit of control achieved, have been installed either with new equipment or in anticipation of or in response to abatement action on the part of authorities. It is safe to say that new steelworks apparatus is designed for and equipped with dust-collection equipment as a matter of course. Coke plants are a thorny exception.

Gaseous emissions arise principally from the conversion of coal to coke, from the reactions of ironmaking slag with the atmosphere, and from the combustion of sulfur-bearing fuels. Remarkably, the biggest fuel-using device in any plant (the blast furnace) cleans sulfur from its own waste gases and releases it through the action of water and air upon the slag. The problems of sulfur dioxide from steaming boilers, from heating furnaces, and from open flames are familiar, and steelmakers tend to seek clean fuels to minimize these emissions. Not so easily controlled are the gases released by the essential operation of coking coal. The gases and vapors around a coke plant include coal smoke and tar fumes, both considered hazardous to humans. The fuel gas produced as a by-product of the coking process contains appreciable hydrogen sulfide which may be stripped only at considerable expense. Steelmakers have made little progress in coping with gaseous air pollutants despite ambitious, often aggressive research conducted both here and abroad for 20 years or more. A great deal of additional technical progress will be needed before present public expectations can be satisfied.

Priorities, Problems, and Opportunities in Pollution-Control Technology

Steelmakers have a major overall problem of satisfying the public's expectations for air quality, and this problem fragments itself into dozens (perhaps hundreds) of sub-problems within each plant. For this reason, air-pollution control is more difficult to attain in steelmaking than in most other industrial operations. Priority is generally given to the specific emission-control problems in the following process segments:

- Coking, especially the charging and pushing of coke ovens
- Steelmaking, especially during use of oxygen
- Sintering, especially highly fluxed practices
- Raw-materials transfers of all kinds
- Casting and handling of hot metal from the blast furnace
- Oxygen scarfing of semifinished steel
- Flushing and disposing of blast-furnace slag
- Utilization or disposal of coke-oven gas.

The above listing is not in any order of priority – each of these problems must be solved.

Contributors to the problems listed above include (1) difficulties in shrouding, hooding, or otherwise accomplishing containment of the emissions; (2) maintenance of the numerous seals and closures required in any containment system; (3) collection of certain materials which are at once abrasive, corrosive, and not amenable to electrostatic precipitation; and (4) disposal of collected materials not suited to some form of recycling. For a few kinds of emissions, notably sulfurous gases from slag, the mechanisms causing the release of fume are not known. This lack of fundamental knowledge also extends in part to generation of iron oxide fumes during steelmaking. It is now generally recognized that metallurgical fumes are different and much harder to collect than pollutants from many other industrial processes. For this reason, public standards based on normal types of problems are frequently inappropriate in one or more ways.

The opportunities for technical gain include improvement of devices for the detection and measurement of air pollutants, but only if these devices are integrated with public standards of adequate compliance. Other opportunities center on the revision or even replacement of problem processes such as coking and sintering, to make them more suited to air-pollution control. Some have suggested that coking as we know it must be made obsolete, but they have not suggested how. Finally, there is an opportunity to unify collection systems, to improve the engineering design of the simpler (and presently less effective) dust-collection devices, and thereby to improve the overall cost and effectiveness of controls.

Section V: Specific Cost/Effectiveness Investigations

Battelle and Swindell-Dressler set out originally to collect and analyze large amounts of cost and effectiveness data representing existing air-pollution controls in steel plants. However, this procedure was retarded by a general shortage of published and other public information on costs and effectiveness, and also by blocks to the transfer of such information from steel companies to outsiders. In view of these blocks, a second approach was taken, based on preparation of engineering estimates of control costs by Swindell-Dressler Company. The estimates were used as the basis of the Phase I work to develop and pretest economic models of control costs as a function of process throughput and effectiveness attained.

Methodology

The Swindell-Dressler estimates were used together with inputs from the steel industry. First, a generalized mathematical model was defined to represent the probable variation of control costs with varying tonnage throughput and control effectiveness. This model may take the form

$$\text{Cost} = A \times (\text{Throughput})^{b} \times (\text{Effectiveness})^{g}$$

where A is a constant of proportionality, and b and g are exponents denoting the sensitivity of costs to changes in throughput and effectiveness, respectively. Other factors may be added as required to depict specific cost situations. It was shown that the above model (as generalized) can represent any orderly, normal system in which either rising throughput or rising effectiveness occasions higher costs. The general model was solved by regression analysis of the Swindell-Dressler data for each of six steelmaking situations, as scaled and expanded by Battelle.

Results and Analysis

The cost-effectiveness data obtained from the steel industry were applied to pretesting of the analysis model, but in most cases there were insufficient examples to establish coherency. The pretest work established that general engineering estimates and models derived from them can represent grouped industry data much better than they can represent individual items within the group. Whereas the average absolute error of all pretests was about 23 percent, the aggregate overall error for all estimates summed was only slightly over 9 percent when compared to cost and effectiveness data supplied by steel companies for use in checking the models. In two cases, it was possible to perform analyses of limited data from industry sources and prove that they could yield coherent cost models. In general, the generic model was verified as applied to real data, and the efficacy of engineering estimation was verified as applied to a grouping of individual cases.

Section VI: Findings and Recommendations

As a result of the experiences gained in collecting, processing, and analyzing cost-effectiveness data, Battelle recommends that NAPCA's Division of Economic Effects Research proceed with a Phase II which should be based on a complete analysis of costs for air-pollution control in steelworks process segments where controls of one kind or another have been widely applied. This Phase II effort should be based mainly upon industry data, and the use of engineering estimates should be minimized. To facilitate the free exchange of information, a method is suggested whereby the steel industry may participate without revealing actual data to NAPCA or to NAPCA's contractor. This may be accomplished by processing data to generate the required cost models under conditions of demonstrably adequate security. Once the data have been processed, and the results examined for coherency, the original data may be discarded or returned to their sources. The guiding principle is that once a coherent model has been formed by regression analysis, the data entering the analysis have no value of themselves and could not really be used in the rest of the cost-projection procedure.

Phases III and IV are outlined in brief. For Phase III, estimates of sensitivity to process throughput and control effectiveness would be used along with both industrial data and engineering cost estimates to prepare cost models for a group of steelworks process segments not generally under good control at this time. In Phase IV, engineering estimation alone would be used with accrued experience to estimate order-of-magnitude costs for the control of air pollution from process segments for which practical control methods do not yet exist. The information from Phase III would have a practical value in national and regional projections; information from Phase IV would measure mainly the degree of present impracticality, because all of the costs would probably be inordinately high.

BLANK PAGE

SECTION III

A PROFILE OF THE AMERICAN STEEL INDUSTRY

The United States produced about 127 million net tons of raw steel in 1967, more than any other nation. The Soviet Union ranked second with 113 million tons, and Japan was third with 68.5 million tons. These three nations, together with the countries of Western Europe, account for over 83 percent of world steel production. (1)*

On a per-capita basis, the U. S. average production of about 1300 pounds of raw steel per person is consistently exceeded by West Germany, Luxembourg, Belgium, Sweden, and Czechoslovakia. Japan exceeded U. S. per capita production for the first time in 1967. (2) The United States imports steel heavily from these countries (except Czechoslovakia), and also from Canada, France, Italy, and the United Kingdom. Total imports of iron and steel exceeded 11.4 million net tons in 1967 and 17.9 million tons in 1968. (3) Imports are becoming a sore subject to U. S. steelmakers, who have been urging Congress to impose limits.

Inasmuch as manufacturing industries and the steel industry are interdependent, steel production is heaviest in the main industrial states, and especially in the belt from Western Illinois to Eastern Pennsylvania. Figure III-1 illustrates the distribution of raw steel production according to geographic divisions established by the American Iron and Steel Institute. (4) Although steel production tends to concentrate near supplies of coal and ore, sparse markets have retarded growth in the mining areas of Wisconsin, Minnesota, and Michigan. Cheap lake transportation has permitted extensive steelmaking developments along the southern shores of Lake Michigan and Lake Erie. The heaviest concentrations of steelmaking extend in strips from Bethlehem to Baltimore, from Pittsburgh to Cleveland, and along the south shore of Lake Michigan. Other active steelmaking centers include Detroit, Buffalo, and Birmingham. Appendix A, following Section VI of this report, lists all steel plants in the United States (as of 1967) by ownership, location, and general type. The number of principal furnaces is also shown as a guide to plant magnitudes, but this number is not definitive because steelmaking furnaces are built in a wide range of sizes. Plants performing only cold operations and heat-treating have been excluded from the Appendix; their air-pollution problems contribute less than the other plants to the problems of the industry.

Most steel in the United States is produced in 49 integrated steel plants** of the type listed in Part I of Appendix A. Integrated plants are outnumbered, however, by smaller secondary steelworks characterized by melting furnaces and small rolling mills. At one time, the remelting of scrap steel was marginally economic except for high-priced products or in the more remote areas of the nation. This is no longer true, because the technology of secondary steelmaking has advanced, and the relative cost of prime remelting stock has declined substantially. The transition may be illustrated by a comparison of the critical prices:

---

*References for this section are given on page III-24.

**See definitions of plant types, footnote to Table I-1.

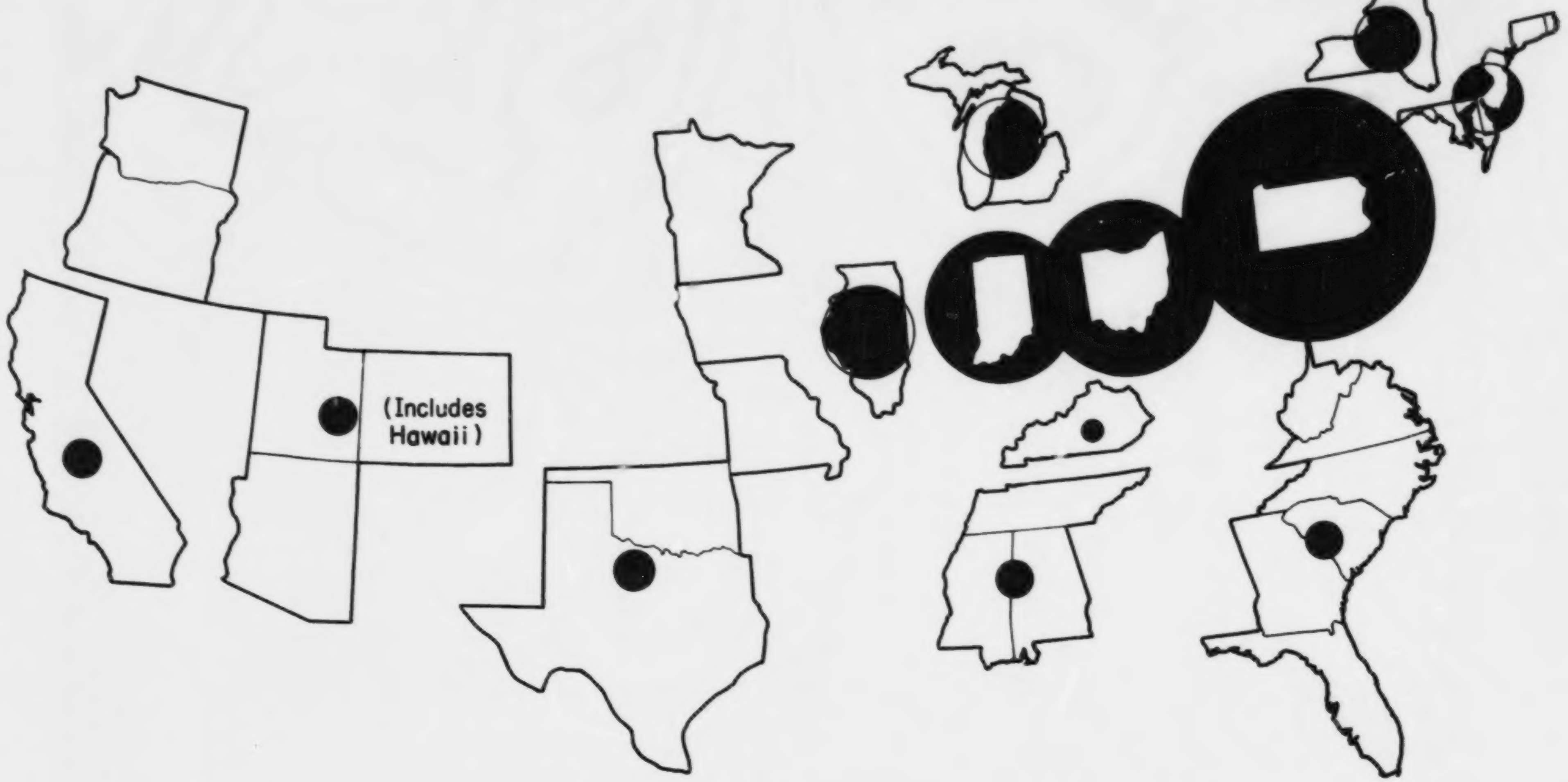


FIGURE III-1. GEOGRAPHIC DISTRIBUTION OF RAW STEEL PRODUCTION IN THE UNITED STATES IN 1967

Diameters of circles correspond to relative output for states and regions shown.

Source: AISI Annual Statistical Report, 1967.

Material	Price per Long Ton[(a)](5) 1952	1967	Percent Change
Iron ore, Mesabi Bessemer, Lake Erie docks	$ 8.45	$ 10.70	+26
Basic pig iron, Mahoning Valley	53.08	63.00	+19
Steel billets, Pittsburgh	64.20	96.40	+50
Hot-rolled strip, Pittsburgh	80.60	122.20	+51
Heavy-melting steel scrap, composite (No. 1)	41.89	27.63	-34

(a) 2240 pounds.

Some forecasters, including Battelle, have indicated that high-tonnage production of steel remelted from scrap will grow sharply during the decade 1971-1980.(6, 7) Relative costs of controlling air pollution for primary versus secondary steelmaking could have an important influence on these developments.

The plants not categorized as either integrated or secondary steelworks include a few isolated coke plants (one is the world's largest), some blast-furnace plants producing pig iron and ferromanganese, and a number of plants which process raw or semifinished steel to salable products. Most large plants of the latter type are captive to and coordinated with large integrated steelworks. Captive steel-processing plants are favored as a way of penetrating new market areas because freight rates for steel-in-process are moderate compared with rates for finished steel. Independent hot-strip mills have all but disappeared since 1960.

Present capital markets do not favor growth of small non-integrated steelmakers to become integrated operations. The last all-new integrated steel company was Kaiser Steel Corporation, formed in the 1940's. There are, however, routes other than direct growth which require less capital. For example, Acme Steel Company at Riverdale, Illinois, experimented with the use of cupolas to provide hot metal for steelmaking, then merged in 1964 with Interlake Iron to obtain hot metal from South Chicago – Interlake had blast-furnace capacity to spare, and a rail connection between the plants was established at modest cost. It remains to be seen whether infusions of capital from conglomerates can help the little steelmakers to grow; Northwestern Industries has acquired Lone Star Steel, and Colt Industries now owns Crucible Steel Corporation of America. On the West Coast, Oregon Steel Mills is undertaking to integrate its electric-arc steelworks by addition of facilities for solid-state reduction of Peruvian iron ores. This venture is technically unique in the U. S., and will be watched closely by the secondary steelmaking industry.(8)

Figure III-2 characterizes the American steel industry by size of enterprise as measured by 1967 sales and operating revenues.(9) In 1950 and later years, this characterization has become blurred by extension of steelmakers into the manufacture of prefabricated buildings and other steel-consuming businesses. (Figure III-2 excludes the captive steelmaking operations of Ford Motor Company and International Harvester's Wisconsin Steel Division; both would probably rank among the top twelve*.)

---

*Both plants have three blast furnaces.

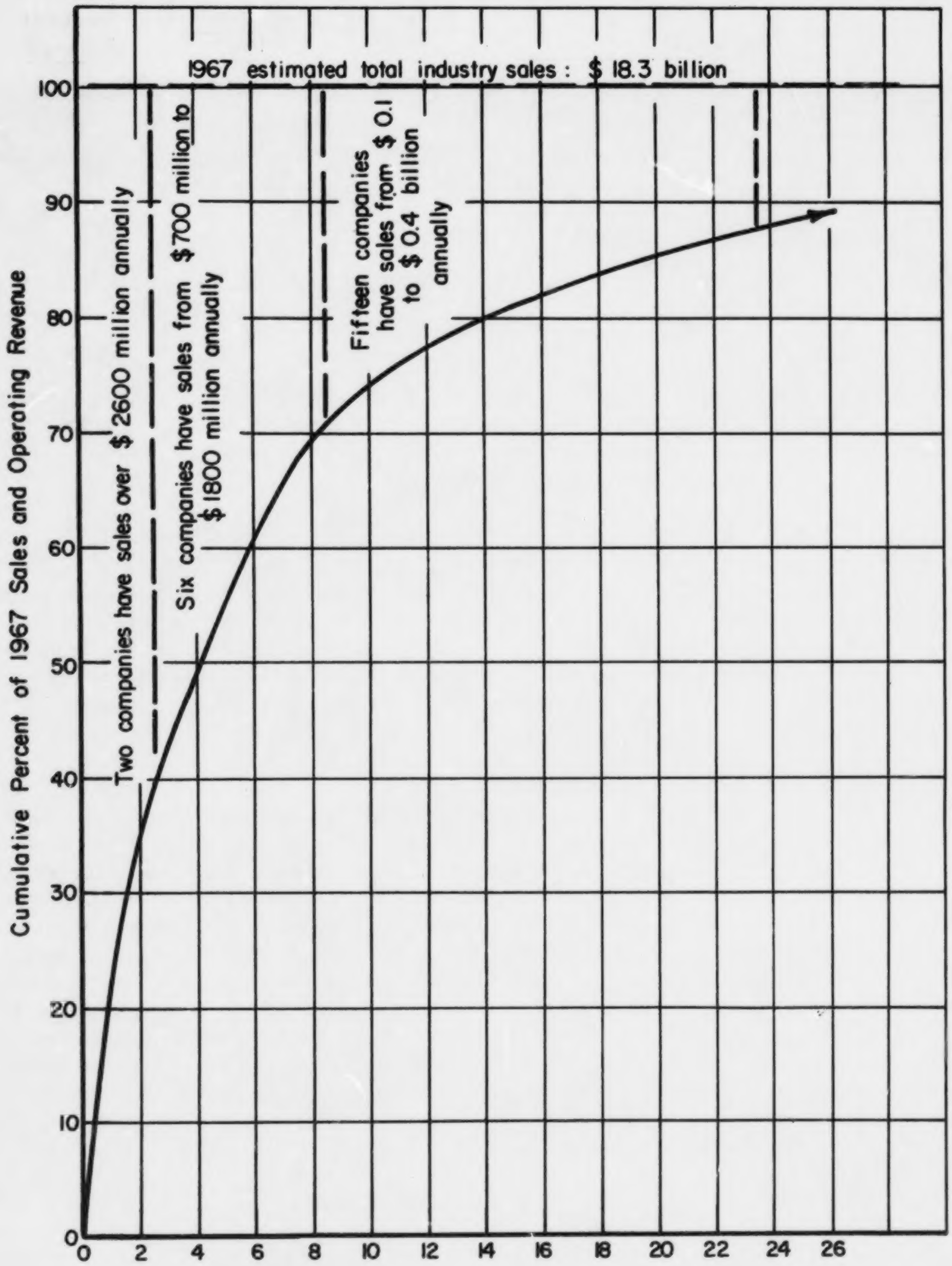


FIGURE III-2. DISTRIBUTION OF STEEL SALES AMONG U. S. COMPANIES, 1967

Source: Iron Age Steel Industry Financial Analysis, 1967.

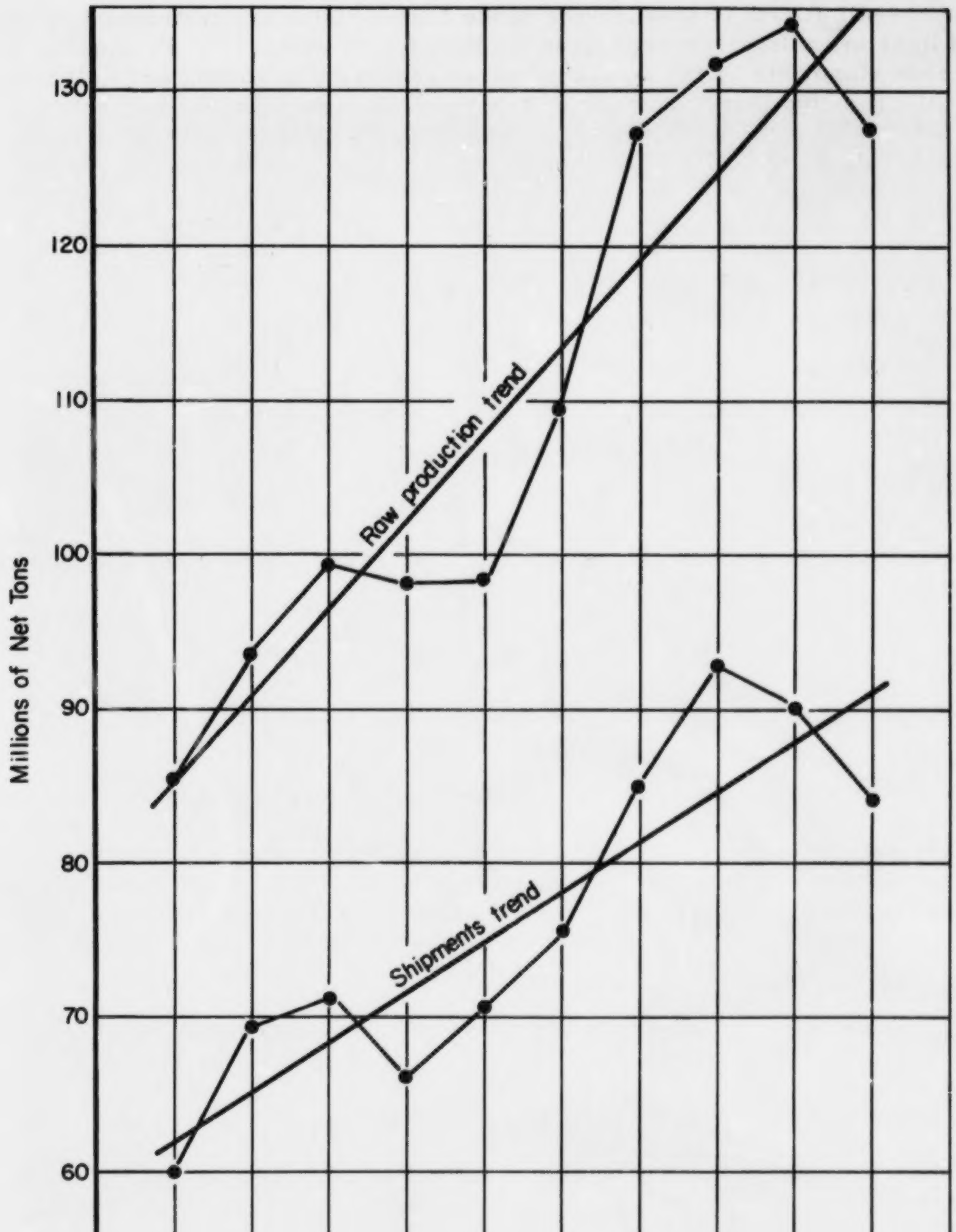


FIGURE III-3. RAW STEEL PRODUCTION AND FINISHED STEEL SHIPMENTS, 1958-67

Source: AISI Annual Statistical Report, 1967.

The overall growth of steelmaking in the United States is illustrated by Figure III-3; the trend lines are a least-squares fit to the data for 10 years.(10) Production of raw steel exceeds shipments by the amount of scrap generated in rolling and finishing steps. Battelle has projected that production of raw steel will reach 157 million net tons annually by 1975, and that the three principal steelmaking processes will share the business as follows(11):

Steelmaking Process	Percent of Raw Steel Production 1965	Percent of Raw Steel Production 1975
Basic open-hearth (integrated)	72.0	37.0
Basic oxygen process (integrated)	17.6	46.0
Other pneumatic (integrated)	0.4	0.0
Electric arc furnace (mainly remelting)	10.0	17.0
Total	100.0	100.0

The trend in process selection is a clear one as of 1969. The trend in tonnage produced is sensitive to changes in the proportion of imports.

INDUSTRY RESOURCES FOR GROWTH AND CHANGE

The growth or revitalization of any independent enterprise depends upon its ability to obtain funds, both from operations and in the capital markets. The resources available to the steel industry may be measured, and the measurement is appropriate because these resources govern the rate and extent to which the industry may respond to demands for better air-pollution controls. The focus in this part of Section III is upon sales, costs, taxes, earnings, dividends and growth of equity, and depreciation allowances. The appropriate questions are as follows:

(1) How well has the steel industry maintained its operating margins in the face of cost pressures?

(2) How much cash does the industry generate?

(3) How have equity investors fared in terms of capital gains and distributions?

(4) What has been the trend in long-term indebtedness?

(5) How do present rates of capital expenditure compare with other capital-intensive industries?

The major source for this part of the study is the American Iron and Steel Institute's Annual Statistical Report for 1967, which presents financial data covering a 10-year period and embracing about 94 percent of crude steel production.(12) (Much of the other 6 percent is produced by Ford Motor Co. and International Harvester.)

Operating Margins

For this analysis, operating margin is defined as the net billing value of products shipped - less labor, materials, freight, purchased services, and other direct costs. Labor applied to non-operating purposes, and income other than from operations, have been omitted. Figures III-4a and III-4b portray total operating margins and margins per net ton of finished steel shipped for each of the 10 years, 1958-1967. The trend line in Figure III-4a is plotted on a least-squares basis.

From the trend of operating margins, it is clear that the price changes in the steel market have not covered the increase in basic costs. In fact, operating revenues per ton steel shipped declined from a 1958-60 average of about \$209.30 to a 1965-67 average of \$208.00.* Perhaps equally revealing is the wide annual fluctuation of margins since 1960. Increasingly, steel-company financial performance has been influenced toward erratic behavior by strike threats in both the steel and automotive industries. When a steelworkers' contract is up for renewal, steel users acquire large hedge inventories and then liquidate them (or buy steel abroad). When an auto strike looms, automakers hedge by overproducing to keep the showrooms full, then slack off after the settlement is reached.

Interestingly enough, the 1958-1960 3-year average of direct labor costs per ton of finished steel was about \$79.80 as compared with a 1965-1967 3-year average of \$78.55. The principal rise has been in costs for materials, supplies, and purchased services, which rose by nearly \$2 per ton of steel between the 1958-1960 and 1965-1967 averaged periods.(13)

The main conclusion from examination of operating margins is that they have become both smaller and more erratic in the past decade.

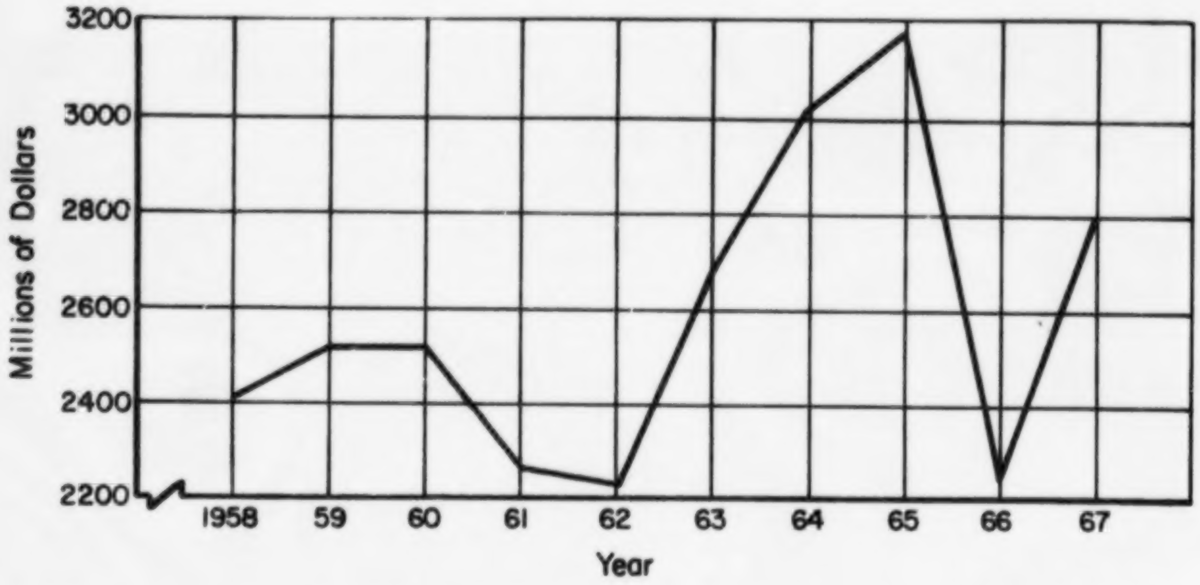
Cash Generation

Net generation of cash is defined for this study as net after-tax income, plus allowances for depreciation, depletion, and amortization. (It is assumed in the case of non-linear depreciations that the tax allowances subtracted from pretax income include a reserve for taxes effectively deferred by depreciation practices.) Figures III-5a and III-5b illustrate the total and unit generations of cash by the steel industry between 1958 and 1967.(14)

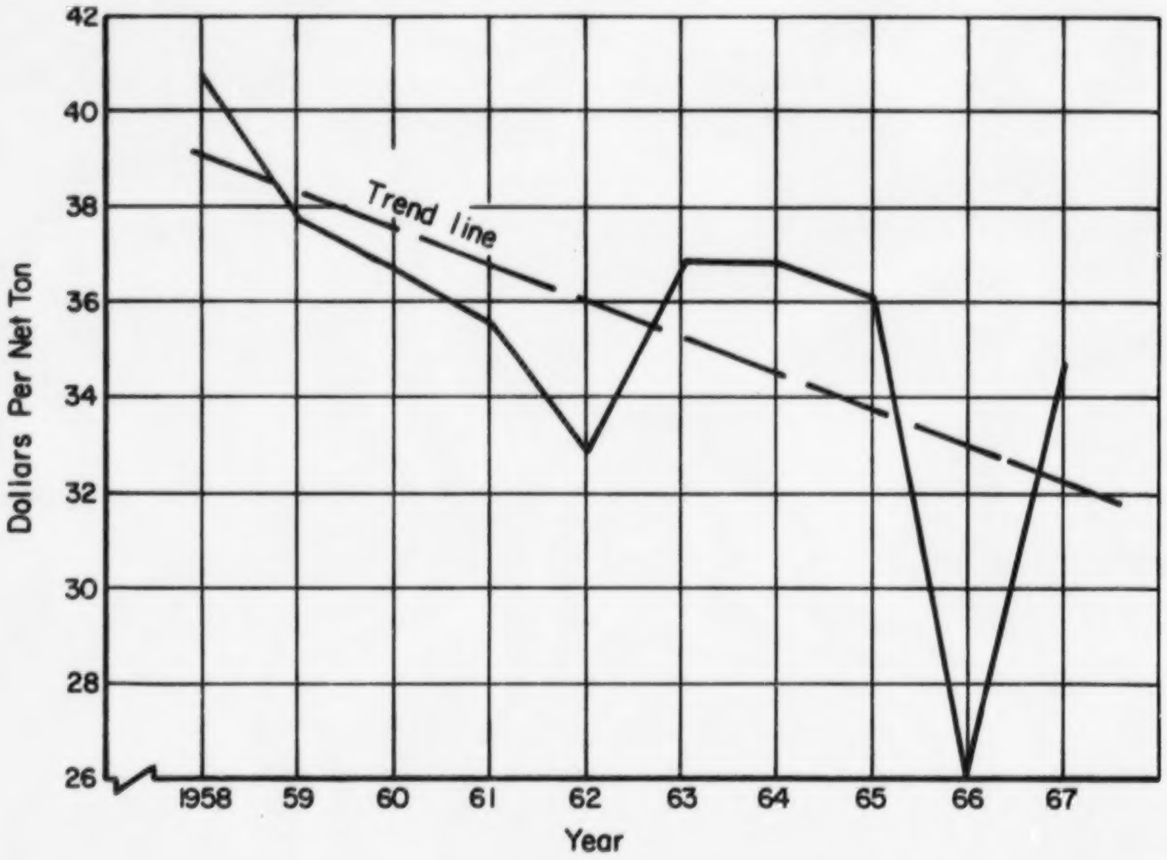
The cash picture is a healthy one. Cash flows in recent years seem to have been more stable than sales and costs, and the trend is clearly upward on a per-ton basis. A major contributor to favorable cash flows is the cut in taxes resulting in part from the 7 percent investment credit enacted in 1962. The total of Federal and state taxes averaged for 1958-1960 was \$16.20 per net ton of steel shipped, as compared with \$11.15 on average for 1965-1967.(15) Investment credits were worth about \$1.55 per ton of shipments in 1967.(16)

---

*In part, this reflects shifts in the product mix, order quantities, and other factors unrelated to pricing.



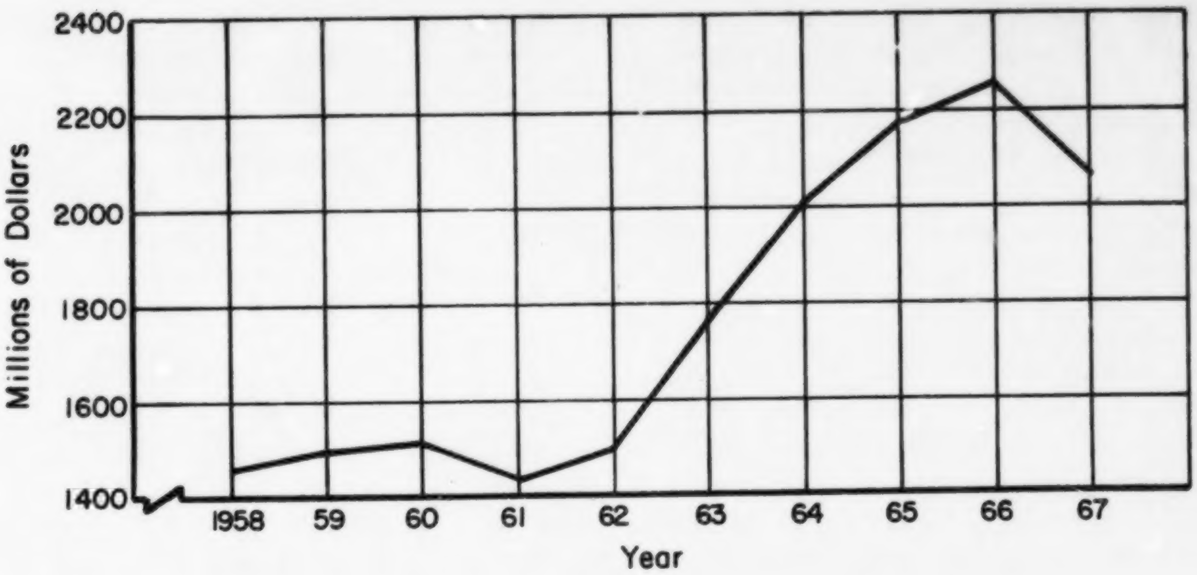
a. Total Operating Margin = Sales Less Direct Labor and Materials Costs



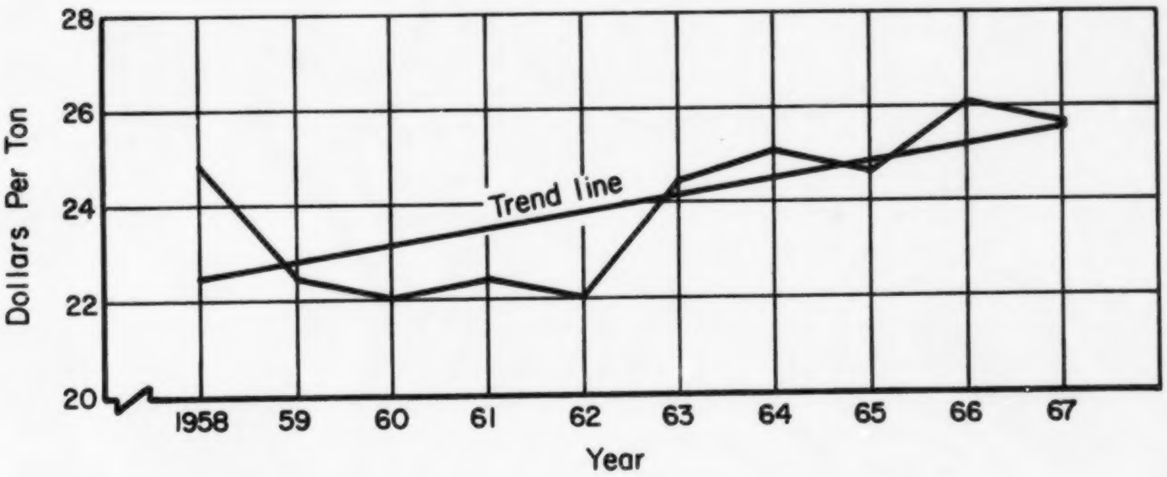
b. Operating Margin Per Net Ton Finished Steel Shipped

FIGURE III-4. OPERATING MARGINS IN THE U. S. STEEL INDUSTRY, 1958-67

Source: AISI Annual Statistical Report, 1967.



a. Total Cash Generated = Net Income Plus Allowances for Depreciation, Depletion, and Amortization



b. Cash Generated Per Net Ton of Finished Steel Shipped

FIGURE III-5. CASH FLOWS GENERATED BY THE U. S. STEEL INDUSTRY, 1958-67

Source: AISI Annual Statistical Report, 1967.

Return on Equity

Annual gain or return on investors' equity may be defined as the sum of dividends paid in cash plus net increases in reinvested earnings. This gain or return, studied as a proportion of total stockholders' equity, indicates the standing of the steel industry as an investment opportunity. Figure III-6 illustrates how steel-industry investors fared from 1958 to 1967.(17) As in the case of operating margins, the graph is characterized by a downtrend and by erratic behavior in recent years. Accordingly, the private investor sees steels as a "depressed" area of the industrial economy and as a doubtful equity investment. In the 3 "wild" years, 1965-1967, average returns on equity amounted to only 6.15 percent, lower than is usually obtained on high-grade bonds. Forbes ranked the steel industry 22nd of 23 industry groups for profitability as of January, 1969.(18)

To counter this bleak picture, steel companies have made an effort to improve their appearance to investors, and stocks of the eight largest companies closed in January, 1969, about 30 percent above their 1968 low points.(19) The major change has been to use straight-line depreciation for accounting purposes, although accelerated methods are still used for tax calculations. Situations of risk have arisen because the capital stock of a number of sound companies (such as Armco) have been selling below book value. Less conservative accounting practices, stable output at healthy levels, appropriate prices, continuation of the investment credit, and a successful repulsion of imports all appear to be necessary if the industry is to gain and hold the investor confidence required for equity financing.

Indebtedness

The ratio of long-term (funded) debt to total assets is a measure of the use of debt by the steel industry in recent years. This ratio is shown in Figure III-7 for the years 1958-1967.(20) The percent relative increase, which has been one of the strong trends, merely confirms the above comments about the industry's problems in attracting equity financing. However, judging from the steadiness of cash flows, the steel industry does not seem to be overextended in debt financing. It is noteworthy that most preferred stocks outstanding at the beginning of the decade have now been retired.(21)

New Capital Spending

In the 3-year period 1958-1960, average new capital spending by steelmakers was about $18.50 per net ton of finished steel shipped, and exceeded the depreciation, depletion, and amortization charges by about $8 per ton or 76 percent. In the 3-year period 1965-1967, capital spending had risen to an average of $23.40 per net ton of shipments, but depreciation charges also rose, and the margin of new spending over depreciation and other writeoffs was down to 70 percent. Accordingly, apparent growth rates through capital spending have not changed much. Some of the increase in total spending is traceable to a rise in the cost index for capital goods over the period. Most of the expended

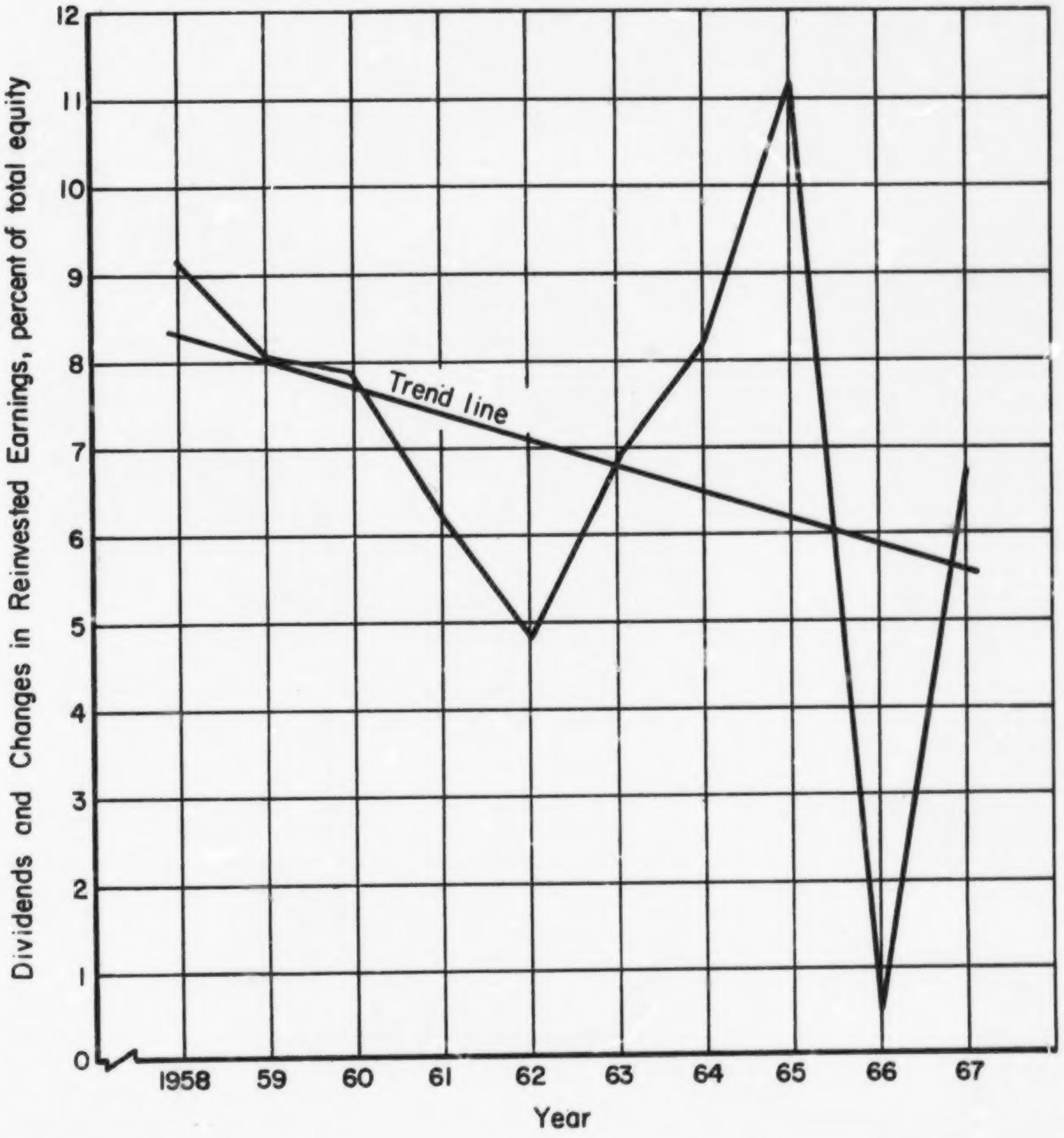


FIGURE III-6. RETURNS ON EQUITY INVESTMENT IN THE U. S. STEEL INDUSTRY

Source: AISI Annual Statistical Report, 1967.

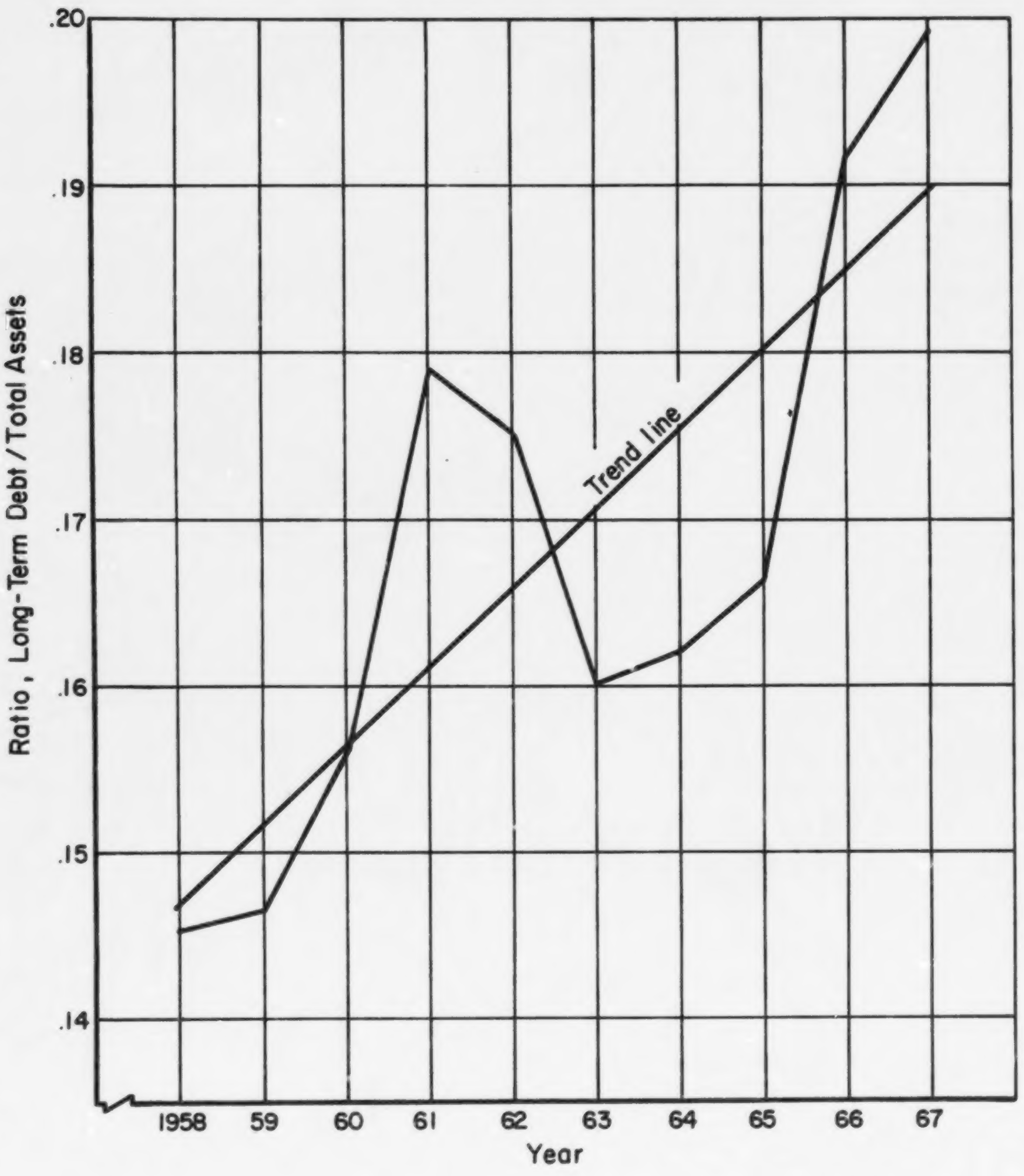


FIGURE III-7. RATIO OF LONG-TERM DEBT TO TOTAL ASSETS IN THE U. S. STEEL INDUSTRY, 1958-67

Source: AISI Annual Statistical Report, 1967.

money has been spent for renewal and modernization. Forbes ranked the steel industry 17th of 23 industries in rate of growth as of January, 1969.(22)

There has been considerable publicity about revitalization and modernization of steelmaking facilities, and remarkable strides have been taken at some plants. In 1969, capital spending by the steel industry will exceed $2300 million for the third year in succession, or roughly 20 percent of total fixed assets in each year. Table III-1 compares capital spending for the iron and steel industry with capital spending in other American industries, and shows that spending by steelmakers has consistently outpaced both the other durables industries and also the comparable oil and chemicals industries.(23, 24)

TABLE III-1. ANNUAL CAPITAL SPENDING AS A PERCENTAGE OF FIXED ASSETS

Source: Chemical Economics Handbook, Stanford Research Institute, current Section 219.2430, April, 1968, and Quarterly Financial Reports, Federal Trade Commission, Securities and Exchange Commission, 4th Quarters 1959, 1960, 1966, and 1967.

Industry Group (U.S.A.)	Annual New Capital Spending, percent of fixed assets Average, 1958-1960	 Average, 1965-1967
Iron and Steel Manufacturing	12.4	15.7(a)
Petroleum and Allied Industries	9.7	10.0
Chemicals and Allied Industries	11.2	13.5
Durable Goods Industries	11.7	14.8
All Manufacturing	11.1	13.3

(a) 1968-1969 proportions are even higher.

Overview

The American steel industry has been concerned about its own future for years, with cause. In the 10 years 1958-1967, labor costs rose by 26 percent per man-hour, and materials costs per ton of finished steel rose by almost 6-1/2 percent. Yet, total revenues per ton of steel shipped did not change markedly. Note that this constant revenue per net ton of steel shipped despite price increases, may be due to a change in the product mix. This change, which resulted in a lesser proportion of high-priced products being shipped may have been caused by the growing influx of steel imports. During this 10-year period, the squeezes were met by outstanding technical performance coupled with substantial new investments in mechanization, expansion of capacity, and automation. The results are apparent in a steady growth in cash flows generated. Tax relief related to investments has been instrumental in fostering the changes required.

Nonetheless, earnings and return on equity have sagged badly, and have become quite erratic as a result of uneven market conditions. Imports of steel, once trivial, have become the principal competition to both coastal and inland producers. The industry has been responding with even heavier spending on new facilities and better equipment. Private investors have been disinterested in steel's troubles, at least until recently – a great share of steelmaking growth and change has been based upon long-term debt. This can tend to further depress earnings on equity and to increase the erratic effects of leverage.

Because high new capital costs for additional air-pollution controls are expected to confront steelmakers within the next decade, some additional money must be found. It must be expected that steel prices will adjust as required to meet costs of operation and to pay for new hardware, on a basis that will leave the industry attractive to sources of equity financing.

DISTRIBUTION OF COSTS IN A HYPOTHETICAL STEELWORKS

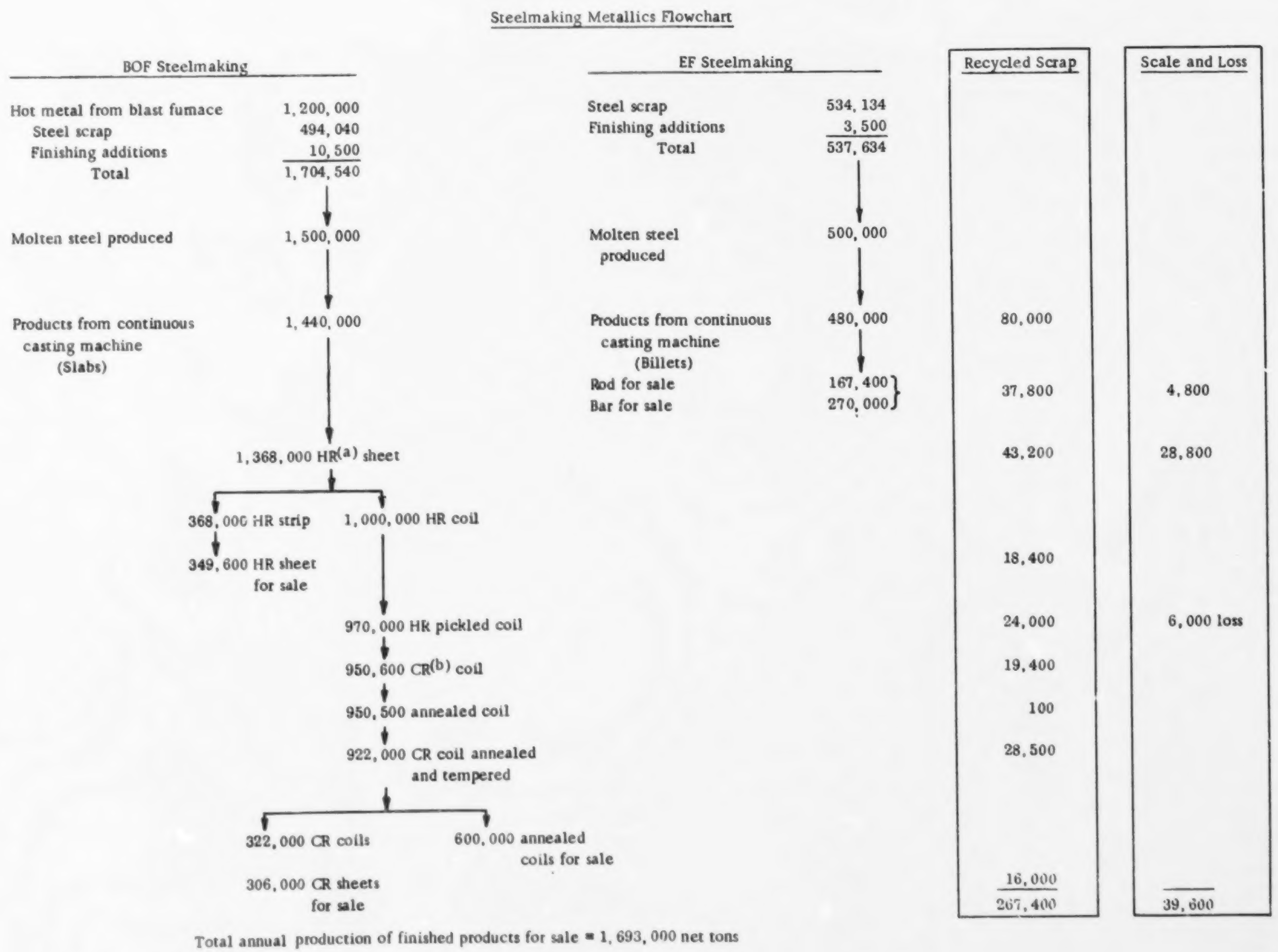
Introduction

Studies of costs for air-pollution control gain perspective if they may be referred to other elements of the cost of producing finished steel from iron ore. To facilitate NAPCA'S study of the operating costs for making steel in the United States, Hypothetical Steel Corporation was "established" in Ohio, near Lake Erie, with an annual production capacity of just under 2 million tons of raw steel. The capital investment for this all-new plant was estimated at $600 million, or $300 per ton of annual capacity for raw steel.

The Hypothetical Steel Corporation's Ohio plant produces 1.5 million tons of molten steel in a basic oxygen furnace (BOF) and 0.5 million tons of molten steel in the electric arc steelmaking furnace (EF). A flowsheet showing the assumed product mix is given in Figure III-8. The molten steel from the BOF is continuously cast into slabs for the production of flat products. The molten steel from the electric furnace is continuously cast into billets for the production of rod and bar. The total annual production of finished products was taken to be 1,693,000 net tons. Recycled steel scrap from the casting and finishing operations was estimated to be 267,400 net tons.

Costs: Raw Materials

The costs of producing iron and steel are broken down into four major items: (1) major raw materials costs, (2) costs above raw materials, (3) fixed charges, and (4) sales and administration costs.


Steelmaking Metallics Flowchart
BOF Steelmaking
Hot metal from blast furnace 1,200,000
Steel scrap 494,040
Finishing additions 10,500
Total 1,704,540
Molten steel produced 1,500,000
Products from continuous casting machine (Slabs) 1,440,000
1,368,000 HR(a) sheet
368,000 HR strip
349,600 HR sheet for sale
1,000,000 HR coil
970,000 HR pickled coil
950,600 CR(b) coil
950,500 annealed coil
922,000 CR coil annealed and tempered
322,000 CR coils
306,000 CR sheets for sale
600,000 annealed coils for sale
EF Steelmaking
Steel scrap 534,134
Finishing additions 3,500
Total 537,634
Molten steel produced 500,000
Products from continuous casting machine (Billets) 480,000
Rod for sale 167,400
Bar for sale 270,000
Recycled Scrap
80,000
37,800
43,200
18,400
24,000
19,400
100
28,500
16,000
267,400
Scale and Loss
4,800
28,800
6,000 loss
39,600
Total annual production of finished products for sale = 1,693,000 net tons

(a) HR = hot-rolled.
(b) CR = cold-rolled.

FIGURE III-8. FLOW CHART FOR 1,693,000 NET TONS OF PRODUCTS PER YEAR FOR HYPOTHETICAL STEEL CORPORATION'S PLANT IN OHIO

Principal raw materials for ironmaking for the Hypothetical plant include taconite pellets, coal, limestone, and oil for injection into the blast furnace. For steelmaking, the principal raw materials are metallics (steel scrap, hot metal, and finishing alloy additions). For casting, rolling, and finishing, the principal raw material is molten or semi-finished steel generated within the plant.

The prices and amounts of some major items consumed in the Hypothetical Steel Corporations's Ohio plant are given in Table III-2. These costs were not summed because the total would include duplications and would not be representative of the actual cost. For example, all of the coal is converted to coke before consumption in the blast furnace. Over 50 percent of the limestone is converted to burnt lime and then is consumed in the steelmaking furnaces. The value of recycled scrap is established for internal bookkeeping, and does not represent an expenditure for steelmaking materials.

TABLE III-2. PRICES AND AMOUNTS OF MAJOR ITEMS CONSUMED IN THE HYPOTHETICAL STEEL CORPORATION'S OHIO PLANT

Item	Amount, net tons per year	Nominal Unit Cost, dollars per net ton	Total Materials Cost per Year, dollars
Taconite pellets	1,920,000	$ 13.64	$26,188,800
Coal(a)	1,036,800	10.02	10,388,736
Coke	720,000	15.72(b)	11,318,400
Limestone(c, d)	650,000	2.20	1,430,000
Finishing additions	14,000	202.00 avg.	2,828,000
Oil	48,000	17.10	8,208,000
Oxygen	125,000	12.00	1,500,000
Electrodes	2,375	582.00	1,382,250
Steel scrap	1,028,174		
Purchased	760,474	$ 26.30(e)	20,000,466
Recycled	267,400	25.00(f)	6,685,000

(a) Coal is used to produce coke for blast-furnace production of pig iron.

(b) Materials and operating cost only. Fixed charges on coke plant and auxiliaries add at least $2 per ton of coke.

(c) Limestone is used as flux in the blast furnace. Limestone is also used to produce burnt lime for the steelmaking furnaces.

(d) Burnt lime made from this limestone is valued at $16 per net ton.

(e) The price for purchased scrap is based on a mixture of grades that is considered suitable for either BOF or EF steelmaking.

(f) The valuation of recycled scrap is for internal bookkeeping and may be assigned at any reasonable level.

Costs Above Raw Materials

The cost above raw materials (sometimes called conversion cost) includes all items other than raw materials, fixed charges, and sales and administration costs. The nature of most "cost-above" items tabulated below is self-evident:

(1) Electric power and oxygen for steelmaking furnaces

(2) Graphite electrodes for electric furnace steelmaking

(3) Burnt lime for steelmaking furnaces

(4) Refractories for furnaces and ladles

(5) Repairs and maintenance

(6) Direct and indirect labor

(7) Utilities, including water and natural gas, plus electric power used for purposes other than melting

(8) Miscellaneous supplies including tools, lubricant, and chemicals for laboratory analyses

(9) Yard switching and slag disposal

(10) General production overhead.

The items of cost-above for iron and steel production were determined item by item, and are illustrated in Tables III-3 through III-5. For casting, rolling, and finishing, the cost-above has been shown as a lump sum, as in Tables III-6 through III-9.

Total Annual Costs and Revenues

The summary of estimated total annual costs and revenues for the Hypothetical Steel Corporation's Ohio plant is given in Table III-10. The total annual operating cost as detailed in Tables III-3 through III-9 is $127.4 million, or about 58 percent of sales. Fixed charges (based on 12 percent of the capital investment of $600 million*) total $72 million per year, or about 33 percent of sales. Sales and administration costs (based on 5 percent of the selling price of finished products) are $11 million. The total annual cost for manufacturing and marketing finished steel is $210.5 million. Income from sales is $221.1 million; the profit prior to income taxes is about 4 percent of sales, and the return on capital investment before income taxes is 1.8 percent. These returns are low, primarily because of high fixed charges in the all-new plant. Existing U. S. plants were built for typically $250 or less per ton of annual capacity, whereas a new plant in 1969 typically could cost up to $350 or more per ton of annual capacity.

---

*Fixed charges include amortization, interest, local taxes, and insurance. Fixed charges on an annual basis were taken as a minimum 12 percent of the total capital cost. A generally descriptive but flexible breakdown could be 5 percent for depreciation, 5.5 percent for interest, and 1.5 percent for local taxes and insurance.

TABLE III-3. ESTIMATED OPERATING COST FOR MAKING HOT METAL IN HYPOTHETICAL STEEL CORPORATION'S OHIO BLAST FURNACE AT A RATE OF 1,200,000 NET TONS PER YEAR

Item	Unit Cost	Net Tons per Net Ton Hot Metal	Operating Cost per Net Ton Hot Metal	
Materials				
Taconite pellets	$13.64/NT	1.60	$21.82	
Coke (see below)	15.72/NT	0.60	9.43	
Limestone	2.20/NT	0.26	0.57	
Oil	17.10/NT	0.04	0.68	
Excess gas credit	--	--	(0.71)	
Dust and sludge credit	--	--	(0.06)	
Subtotal for materials				$31.73
Cost Above				
Labor	$5.00/man-hour		0.50	
Utilities			1.00	
Refractories			0.15	
Distributed reline cost			0.60	
Maintenance and repairs			0.75	
Miscellaneous supplies			0.78	
General overhead			0.45	
Subtotal for cost above				$ 4.23
Total operating cost (excluding fixed charges)				$35.96

Estimated Cost of Producing One Net Ton of Coke

Item	Unit Cost	Net Tons per Net Ton Hot Metal	Operating Cost per Net Ton Hot Metal	
Coal	$10.02/NT	1.44/NT	$14.43	
Credits for coke breeze, coke-oven gas, and coal chemicals			(4.71)	
			9.72	
Cost above			6.00	
Total operating cost for coke (excluding fixed charges)				$15.72

TABLE III-4. ESTIMATED OPERATING COSTS FOR STEELMAKING IN A BOF SHOP WITH AN ANNUAL CAPACITY OF 1,500,000 NET TONS OF MOLTEN STEEL

Item	Unit Cost	Requirements per Net Ton Steel	Operating Cost per Net Ton of Molten Steel	
Metallics				
Hot metal	$ 35.96/NT	0.791 NT	$28.41	
Steel scrap	26.30/NT	0.339	8.92	
Finishing additions	202.00/NT average	0.007	1.41	
Subtotal for metallics				$38.74
Cost Above				
Burnt lime	$ 16.00/NT	130 pound	1.04	
Refractories	--	--	1.34	
Oxygen	12.00/NT	148 pound	0.89	
Labor	$ 5.00/man-hour	0.60 man-hour	3.00	
Repairs and maintenance			2.00	
Utilities			0.40	
Yard switching and slag disposal			0.45	
Miscellaneous supplies and service			0.40	
General overhead			0.50	
Subtotal for cost above				$10.02
Total operating cost for molten BOF steel (excluding fixed charges)				$48.76

TABLE III-5. ESTIMATED OPERATING COSTS FOR STEELMAKING IN AN ELECTRIC FURNACE SHOP WITH AN ANNUAL CAPACITY OF 500,000 NET TONS OF MOLTEN STEEL

Item	Unit Cost	Requirements per Net Ton Steel	Operating Cost per Net Ton of Steel	
Metallics				
Steel scrap	$ 26.30/NT	1.068 NT	$28.09	
Finishing addition	202.00/NT average	0.007 NT	1.41	
Subtotal for metallics				$29.50
Cost Above				
Electric power	$ 0.008/kilowatt-hour	480.0 kilowatt-hour	3.84	
Electrodes	0.291/pound	9.5 pound	2.76	
Burnt lime	16.00/NT	0.04/NT	0.64	
Refractories	--	--	1.60	
Oxygen	12.00/NT	11.0 pound	0.07	
Repairs and maintenance	--		1.80	
Labor	5.00/man-hour	0.8 man-hour	4.00	
Utilities			0.45	
Yard switching and slag disposal			0.40	
Miscellaneous			0.35	
General overhead			0.50	
Subtotal for cost above				$16.41
Total operating cost for molten electric furnace steel (excluding fixed charges)				$45.91

TABLE III-6. ESTIMATED OPERATING COST FOR CONTINUOUS CASTING OF 1,440,000 NET TONS OF SLABS AND 480,000 NET TONS OF BILLETS

Item	Amount, net tons per year	Unit Cost	Total Operating Cost per Year	Total Operating Cost per Net Ton Billets and Slabs	
		Continuously Cast Billets			
Major Materials					
Molten steel	500,000	$ 45.91/NT	$22,955,000	$47.82	
Scrap (credit)	(20,000)	(25.00)/NT	(500,000)	(1.00)	
Subtotal major materials					$46.82
Cost Above					4.50
Total operating cost per net ton of billets (excluding fixed charges)					$51.32
		Continuously Cast Slabs			
Major Materials					
Molten steel	1,500,000	$ 48.76/NT	$73,140,000	$50.79	
Scrap (credit)	(60,000)	(25.00)/NT	(1,500,000)	(1.00)	
Subtotal major materials					$49.79
Cost Above					4.00
Total operating cost per net ton of slabs (excluding fixed charges)					$53.79

TABLE III-7. ESTIMATED OPERATING COST FOR MAKING 167,400 NET TONS OF WIRE ROD AND 270,000 NET TONS OF MERCHANT BAR FROM CONTINUOUSLY CAST BILLETS

Item	Amount, net tons per year	Unit Cost	Total Operating Cost per Year	Total Operating Cost per Net Ton of Wire Rod or Bar
		Wire Rod		
Major Materials				
Continuously cast billets	180,000	$51.32/NT	$ 9,237,600	$55.18
Scrap (credit)	(10,800)	(25.00)/NT	(270,000)	(1.61)
Subtotal major materials				$53.57
Cost Above				14.75
Total operating cost per net ton of wire rod (excluding fixed charges)				$68.32
		Merchant Bar		
Major Materials				
Continuously cast billets	300,000	$51.32/NT	$15,396,000	$57.04
Scrap (credit)	(27,000)	(25.00)	(675,000)	(2.50)
Subtotal major materials				$54.54
Cost Above				12.25
Total operating cost per net ton of merchant bar (excluding fixed charges)				$66.79

TABLE III-8. ESTIMATED OPERATING COST FOR HOT-ROLLED COILS AND SHEETS

Item	Amount, net tons per year	Unit Cost	Total Operating Cost per Year	Total Operating Cost per Net Ton of Hot-Rolled Coil and Sheet
		Hot-Rolled Coils		
Major Materials				
Slabs	1,440,000	$53.79	$77,457,600	$56.62
Scrap (credit)	(43,200)	(25.00)	(1,080,000)	(0.79)
Subtotal major materials				$55.83
Cost Above				7.20
Total operating cost per net ton of hot-rolled coils (excluding fixed charges)				$63.03
		Hot-Rolled Sheet		
Major Materials				
Hot-rolled coils	368,000	$63.03	$23,195,040	$66.35
Scrap (credit)	(18,400)	(25.00)	(460,000)	(1.32)
Subtotal major materials				$65.03
Cost Above (for shearing)				3.50
Total operating cost per net ton of hot-rolled sheet (excluding fixed charges)				$68.53

TABLE III-9. ESTIMATED OPERATING COST FOR COLD-ROLLED COILS AND SHEET

Item	Amount, net tons per year	Unit Cost	Total Operating Cost per Year	Total Operating Cost per Net Ton of Product	
Pickled Hot-Rolled Coils					
Major Materials					
Hot-rolled coils	1,000,000	$63.03	$63,030,000	$64.97	
Scrap (credit)	(24,000)	(25.00)	(600,000)	(0.62)	
Subtotal major materials					$64.35
Cost Above					3.50
Total operating cost per net ton of pickled coils					$67.85[a]
Cold-Rolled Coils					
Major Materials					
Pickled coils	970,000	$67.85	$65,814,500	$69.23	
Scrap (credit)	(19,400)	(25.00)	(485,000)	(0.51)	
Subtotal major materials					$68.72
Cost Above (cold rolling)					3.75
Total operating cost per net ton of cold-rolled coils					$72.47[a]
Annealed Cold-Rolled Coils					
Major Material					
Cold-rolled coils	950,600	$72.47	$68,889,982	$72.47	
Cost Above (for annealing)				2.50	
Total operating cost per net ton of annealed cold-rolled coils					$74.97[a]
Annealed and Tempered Cold-Rolled Coils					
Major Materials					
Annealed cold-rolled coils	950,600	$74.97	$71,266,482	$77.30	
Scrap (credit)	(28,600)	(25.00)	(715,000)	(0.78)	
Subtotal major materials					$76.52
Cost Above (tempering)					3.00
Total operating cost per net ton of annealed and tempered coils					$79.52[a]
Cold-Rolled Sheet					
Major Materials					
Tempered cold-rolled coils	322,000	$79.52	$25,605,440	$83.68	
Scrap (credit)	(16,000)	(25.00)	(400,000)	(1.31)	
Subtotal major materials					$82.37
Cost Above (shearing)					3.50
Total operating cost per net ton of cold-rolled sheet					$85.87[a]

(a) Product cost does not include fixed charges.

TABLE III-10. SUMMARY OF ESTIMATED COSTS AND REVENUES FOR HYPOTHETICAL STEEL CORPORATION'S OHIO PLANT

Products	Quantity	Operating Cost		Sales Price, dollars per net ton	Revenue, dollars per year
		Per Net Ton	Per Year		
Wire rod	167,400	$68.32	$ 11,436,768	$130.00	21,762,000
Merchant bar	270,000	66.79	18,033,300	126.00	34,020,000
Hot-rolled sheets	349,000	68.53	23,958,088	117.00	40,903,200
Cold-rolled sheets	306,000	85.87	26,276,220	144.00	44,064,000
Cold-rolled coils	600,000	79.52	47,712,000	134.00	80,400,000
	1,693,000		$127,416,376		221,149,200

Overall Manufacturing and Sales Costs

Total operating costs	$127,416,376
Fixed charges, 12 percent of capital investment ($600 million)	72,000,000
Sales and administration, 5 percent of selling price of finished products	11,057,400
Estimated overall costs (excluding Federal income taxes)	$210,473,776

REFERENCES

(1) Stahl und Eisen, Heft 9, Jahrgang 88, May 2, 1968, seite 465.

(2) Ibid.

(3) American Metal Market, 76, No. 23, February 5, 1969, p 1.

(4) American Iron and Steel Institute, Annual Statistical Report, 1967, New York, 1968, page 68.

(5) American Metal Market Company, Metal Statistics 1968, 61st ed., New York, 1968, pp 175, 185, 285, 288, and 306.

(6) Sims, C. E., "What is Ahead in the Next 25 Years for Electric Furnace Steelmaking", Journal of Metals, 20, No. 2, February, 1968, p 44.

(7) Miller, J. R., "Prereduction and Steelmaking", Address presented to AIME Pittsburgh Chapter, Process Metallurgy Section, February 6, 1969.

(8) Ibid.

(9) "Steel Industry Financial Analysis", Iron Age, April, 1968.

(10) AISI, op. cit., p 8.

(11) Miller, op. cit.

(12) AISI, op. cit., pp 9, 10, 11.

(13) Ibid., p 10.

(14) Ibid.

(15) Ibid.

(16) Iron Age, op. cit.

(17) AISI, op. cit., pp 9, 10 (some data from 1966 edition also).

(18) Forbes, Company Group Reports, January 1, 1969, p 164.

(19) McManus, G. J., "Steel's Profit Image", Iron Age, 204, No. 6, February 6, 1969, p 44.

(20) AISI, op. cit., p 9.

(21) Ibid.

(22) Forbes, op. cit., p 164.

III-25 and III-26

(23) Chemical Economics Handbook, Stanford Research Institute, current section 219.2430, April, 1968.

(24) Quarterly Financial Reports, FTC-SEC, U. S. Dept. of Commerce, 4th Quarter Issues for 1959, 1960, 1966, and 1967.

BLANK PAGE

SECTION IV

THE TECHNICAL DETERMINANTS OF AIR-POLLUTION CONTROL COST

This section presents an abbreviated general outline of air-pollution control technology as background for the cost studies. More detail on all of these discussions may be found in the companion Final Technological Report.

Receipt, Storage, and Handling of Raw Materials

Raw materials (principally coal, ore, and limestone) usually are crushed at their points of origin and sized prior to shipment. Conventionally, ore is crushed to a 4-inch top size, limestone is crushed and sized to a typical range of 1-1/2 by 2-1/2 inches, and coal is crushed to a top size of 1 inch or finer. There is a trend to perform additional crushing and sizing of ores at the mines so that the ore as shipped is ready for charging to blast furnaces. If crushing and screening are performed at the steelworks, shrouding is required to hold dust losses to a minimum. Raw materials are received at the steelworks via lake or ocean freighter, by barge, or by truck or railroad car.

Open stockpiles of coal (1/2 to 1 inch is a common top size) may reach a height of 100 feet and cover up to 10 acres. They can be serious sources of dust during windy weather. In comparison to coal, stockpiles of ore and limestone are considered to be less serious sources of emission because the materials are denser and typically coarser in size. No truly effective control exists for dust blow-off from stockpiles of coal. Spraying with pitch, oil, or plastics, sometimes used on the dustier coals, is of limited effectiveness because the piles are constantly being broken by addition or removal of material. The large scale of most stockpiles makes it impractical to consider shrouding the entire area. Fine ores intended for sintering contain appreciable dust and are sometimes wetted to maintain some control over dusting.

Transfers from stockpiles into steel-plant operations are usually by means of overhead clam-bucket gantry cranes to bottom-dump cars operating on elevated railways, or by endless rubber belts for upward movement and gravity chutes for downward movement. Dust is created at each transfer point. Outdoor belts are usually covered but not enclosed, and dust blow-offs can occur during transport of the materials. Emission control at indoor transfer points may be achieved with cyclone dust collectors. In Japan, free-fall dusting in the transfer of coal is minimized by underground reclaiming from stockpiles; this practice is not in general use in the U. S.

Massive scrap metal must sometimes be cut up to size it for charging into steelmaking furnaces. Cutting is done outdoors with oxygen torches. Often the preheat is lost when the lance is moved, whereupon the oxygen jet contacts cold metal. This results in the evolution of iron oxide fumes. The total amount of fume from this operation and the amount of iron oxide dust generated from handling scrap is relatively small, but locally can be quite dense at times. No emission control ordinarily is used in these operations.

Fugitive dust from handling of raw materials during receiving, from wind-swept stockpiles, and from free fall at transfer points is under generally poor control. The usual motivation to prevent or contain dusting is to improve recovery for economic reasons, to improve housekeeping (coal dust is a fire hazard), and to reduce fall-out in areas adjoining the mill.

Coking

Coke is the principal fuel of the blast furnace, and the most important source of energy in integrated steelmaking. Unfortunately, the charging and pushing of coke ovens is one of the major uncontrolled sources of air pollution in an integrated steelworks. Practical methods for effective control of coke-plant emissions are not yet in sight.

Nearly all metallurgical coke is made in by-product ovens. In the use of by-product ovens, volatile matter released by heating coal in the absence of air is processed to recover tar, ammonia, and solvents. After the extraction of these, a medium-Btu fuel gas remains. This gas may be used for underfiring the coke ovens, as well as for heating elsewhere in the steel plant. Coke-oven gas is free of particulates, but usually contains hydrogen sulfide.

A modern coke oven receives a charge of 10 to 30 tons of coal through ports at the top. Each oven may be 10 to 18 feet high, 30 to 60 feet deep, and 14 to 20 inches wide, and as many as 100 ovens may be set together in a battery. Flues between the ovens carry hot gases which heat the oven walls to an incandescent temperature. The charged coal usually has a top size of 1/8 inch. After a coking period of 16 to 20 hours, doors at both ends of the oven are opened and a ram pushes the coke, now typically 4-inch pieces, into special railway cars. At a quenching tower, the hot coke is deluged with water to cool it. The coke is then screened to size and sent to the blast furnaces. A flow sheet for a typical by-product coke plant is presented in Figure IV-1.

The gases and volatiles released from coal during coking are drawn into ascension pipes at the ends of the coke ovens and thence into collector mains. The gases include carbon monoxide, hydrogen, methane, hydrogen sulfide, ammonia, and nitrogen. The volatiles include anthracene and other tarry compounds, benzene, toluene, xylene, naphthalene, phenols, and pitch. Recovery of these by-products starts as the cooled raw gases leave the mains. A flow sheet for a typical by-product plant is given in Figure IV-2.

Charging and Coking

Steam, flame, smoke, and fine coal rush out of the oven ports during charging. During coking, leakage of aromatic vapors may occur at the charging ports and at the end doors. Leakage can be minimized by adequate maintenance of the seals, but a satisfactory solution to the problem of emissions during charging has not been found. Some improvement has resulted from the use of steam jets in the raw-gas ascension pipes to increase the draft on the open oven during charging. An alternate method tried in Europe is the use of a special larry car that drops the coal through sleeves lowered

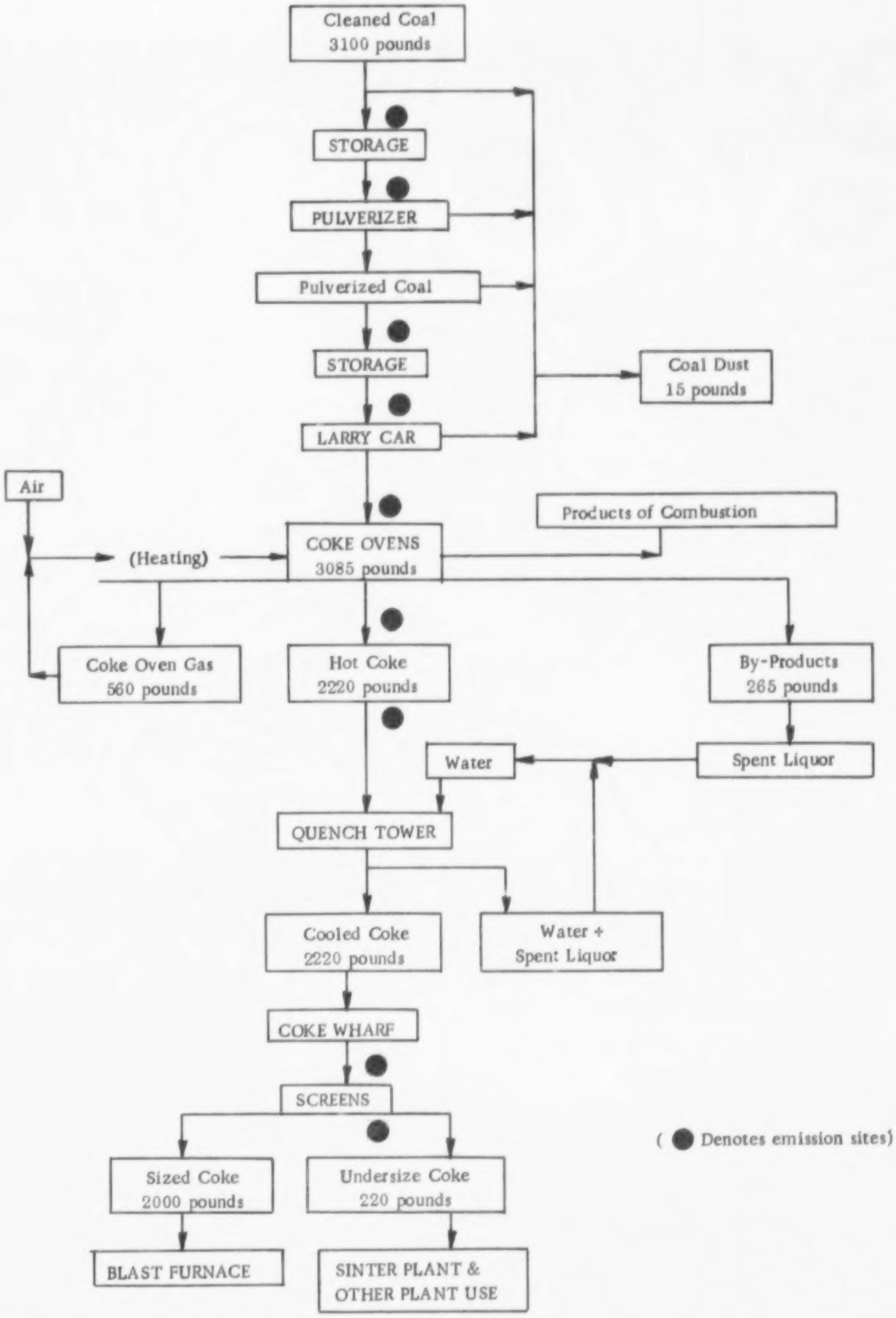

Cleaned Coal
3100 pounds
STORAGE
PULVERIZER
Pulverized Coal
STORAGE
Coal Dust
15 pounds
LARRY CAR
Air
Products of Combustion
(Heating)
COKE OVENS
3085 pounds
Coke Oven Gas
560 pounds
Hot Coke
2220 pounds
By-Products
265 pounds
Water
Spent Liquor
QUENCH TOWER
Cooled Coke
2220 pounds
Water +
Spent Liquor
COKE WHARF
SCREENS
(● Denotes emission sites)
Sized Coke
2000 pounds
Undersize Coke
220 pounds
BLAST FURNACE
SINTER PLANT &
OTHER PLANT USE

FIGURE IV-1. TYPICAL FLOW SHEET FOR A BY-PRODUCT COKE PLANT

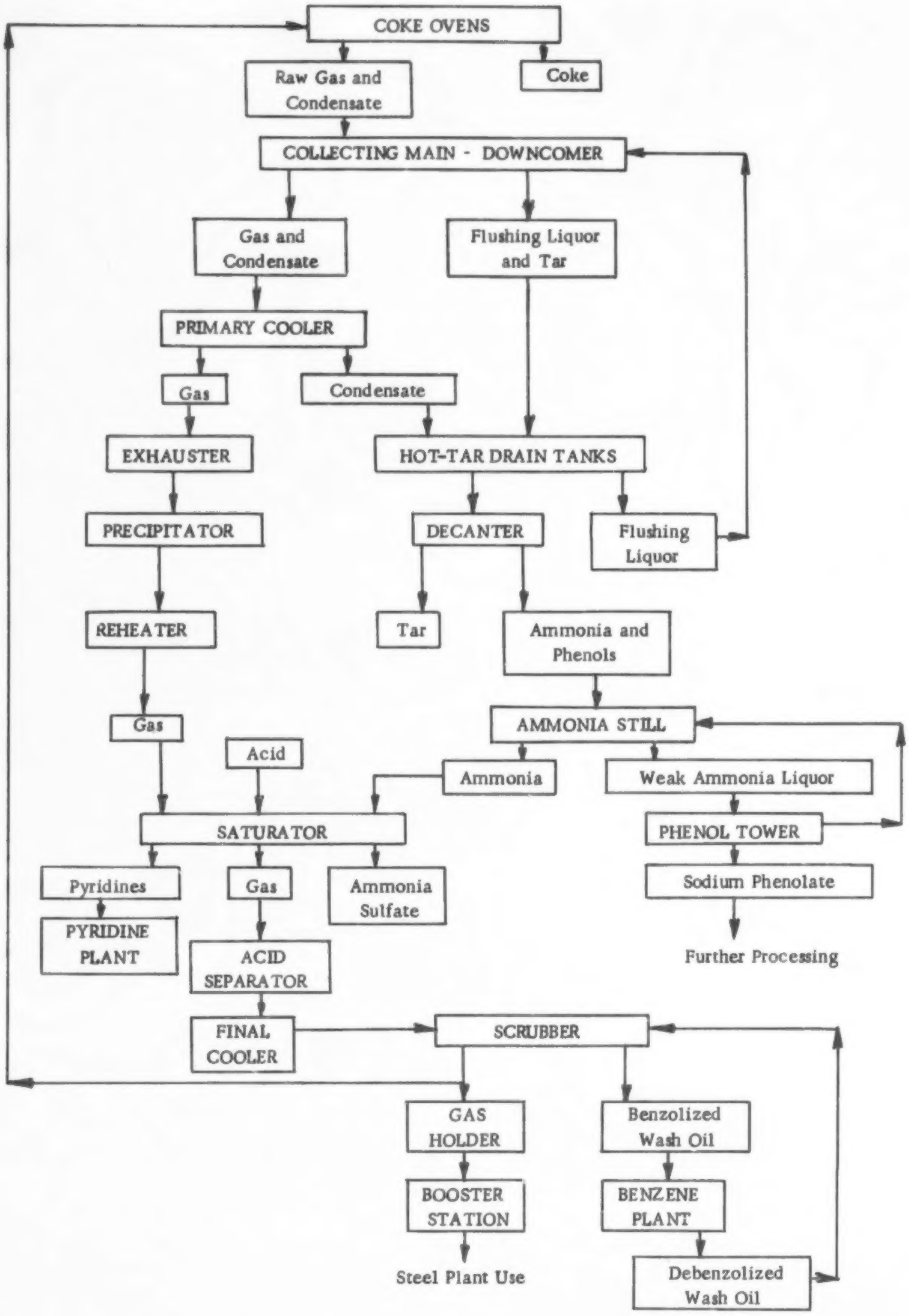

COKE OVENS
Raw Gas and Condensate
Coke
COLLECTING MAIN - DOWNCOMER
Gas and Condensate
Flushing Liquor and Tar
PRIMARY COOLER
Gas
Condensate
EXHAUSTER
HOT-TAR DRAIN TANKS
PRECIPITATOR
DECANTER
Flushing Liquor
REHEATER
Tar
Ammonia and Phenols
Gas
AMMONIA STILL
Acid
Ammonia
Weak Ammonia Liquor
SATURATOR
PHENOL TOWER
Pyridines
Gas
Ammonia Sulfate
Sodium Phenolate
PYRIDINE PLANT
ACID SEPARATOR
Further Processing
FINAL COOLER
SCRUBBER
GAS HOLDER
Benzolized Wash Oil
BOOSTER STATION
BENZENE PLANT
Steel Plant Use
Debenzolized Wash Oil

FIGURE IV-2. BY-PRODUCT PLANT FLOWSHEET

into the oven and collects the emissions in shroud pipes. An attempt is made to burn the vapors with the shroud air, then to wash the waste gases. Structural limitations of present American ovens may not permit direct adoption of this system; in any event it is imperfect. An alternative pneumatic charging method is being worked on in the United States.

Pushing

When the incandescent coke is pushed out of the oven onto an open quench car, a thermal draft is induced in the immediate surroundings. Fine particulates are blown high into the atmosphere. Most of this dust comes from abrasion of the coke during pushing, but there may be smoke from incompletely coked coal. Good coking practice results in reduced emission of smoke during pushing, but does not eliminate dusting. The near-future prospects for development of a pushing system having good control of emissions are poor.

Coke Quenching

The open quench car contains the newly pushed coke on a sloping hopper bottom with side gates made of grating. The car is moved to the quench tower: a large chimney that fits over the car. Water sprays in the chimney deluge and cool the coke, and the rising cloud of steam in the chimney lifts coke dust into the atmosphere. Most of this dust appears to fall out in the vicinity of the tower. Baffles installed in a quench tower will reduce the emission of particulates into the atmosphere by 75 percent or more.

Coke Handling

The quenched coke is dumped onto a sloping brick wharf and conveyed to sizing and screening operations. Steel and rubber shrouding at the transfer points, at the crusher, and at the screens minimize dust loss. Indoor transfer points may utilize a cyclone and fan to collect the dust. Fines are removed before the sized coke is transferred to the blast furnace. The fines are usually transferred to the sinter plant. Compared to charging of the ovens with coal and pushing of the hot coke, dusting during coke handling is not a serious problem, except in windy weather.

By-Product Processing

Usually only minor emissions occur at the primary (hot) end of the by-product system because it is under negative pressure. Some odor of free vapor may be present at the tar collectors and decanters, and at locations where the liquor runs in lines that are not fully closed. Ammonia and organic fumes may be particularly strong at sumps where decanted liquor and other flush liquor is recycled to the sprays for cooling the collector mains. In older plants, the addition of sulfuric acid to the ammonium sulfate precipitator tank can cause fuming.

Tars may contain polycyclic aromatic hydrocarbons which may be hazardous to health. Emissions from vents on tar processing and storage tanks have been led through scrubbers to absorb or destroy the fumes. However, the tars tend to condense and foul the scrubbers. Vapors of the light oils are both toxic and flammable. Condensers and some process tanks are vented, and the sweet aromatic vapors often pervade a large area on calm days. Some leakage is inevitable, but the high fire-hazard level encourages preventive measures irrespective of needs to control air quality.

Preprocessing Raw Materials

Sintering

Sintering plants convert iron-ore fines and metallurgical dusts into an agglomerated product that is coarse enough for charging into the blast furnace. The iron-bearing materials are moistened and mixed with fine coke to form a bed on a slow-moving grate. The bed is kindled under an ignition hood; then a forced draft of air keeps the bed burning until a clinker is formed. Air is blown onto the sinter to cool it after discharge from the main grate. Then the cooled sinter is screened and transported to the blast furnace. Sinter fines are recycled.

Sintering machines process a wide variety of feed materials and produce a considerable amount of emissions. Points of emission in a sinter plant are designated by the circles in the flow sheet in Figure IV-3.

Minor amounts of dust are created in the handling and grinding of raw materials. Other emissions include dust sucked through the grate bars into the windbox, combustion gases from ignition and firing, and dusts generated in the screening and cooling operations. Complete combustion during sintering makes it unlikely that the exhaust gas contains unburned hydrocarbons. However, the coke-oven gas used for ignition and the sulfur in the sinter mix contribute sulfur dioxide to the combustion products. Sinter dust may contain particles of iron oxides, fluxes, and silicates.

Multicyclones, electrostatic precipitators, venturi scrubbers, mechanical collectors, and baghouses have been used in various combinations at the various points of emission.

Control of sintering emissions is considered to be at a low level, especially in manufacture of fluxed sinters. Operation and maintenance costs are high. Control of emissions to a level under 0.05 grain/scf is possible, but clearly expensive.

Pelletizing

Pellets are made by rolling fine iron ores mixed with a binder to form damp balls about 1/2 inch in diameter. The balls are dried and fired to harden them. Pellets are usually made at or near the mine sites, rather than in the steel plants. In this respect, pelletizing differs from sintering, which is usually done at the steel plant.

Concentrates received at the pelletizing plant are moist, and dust generation during receiving is not a problem. Bentonite is received in covered hopper cars and is unloaded in special bins that meter the material into the pelletizing operation. Particulate emissions are magnetite, hematite, and bentonite. The minor amounts of dust

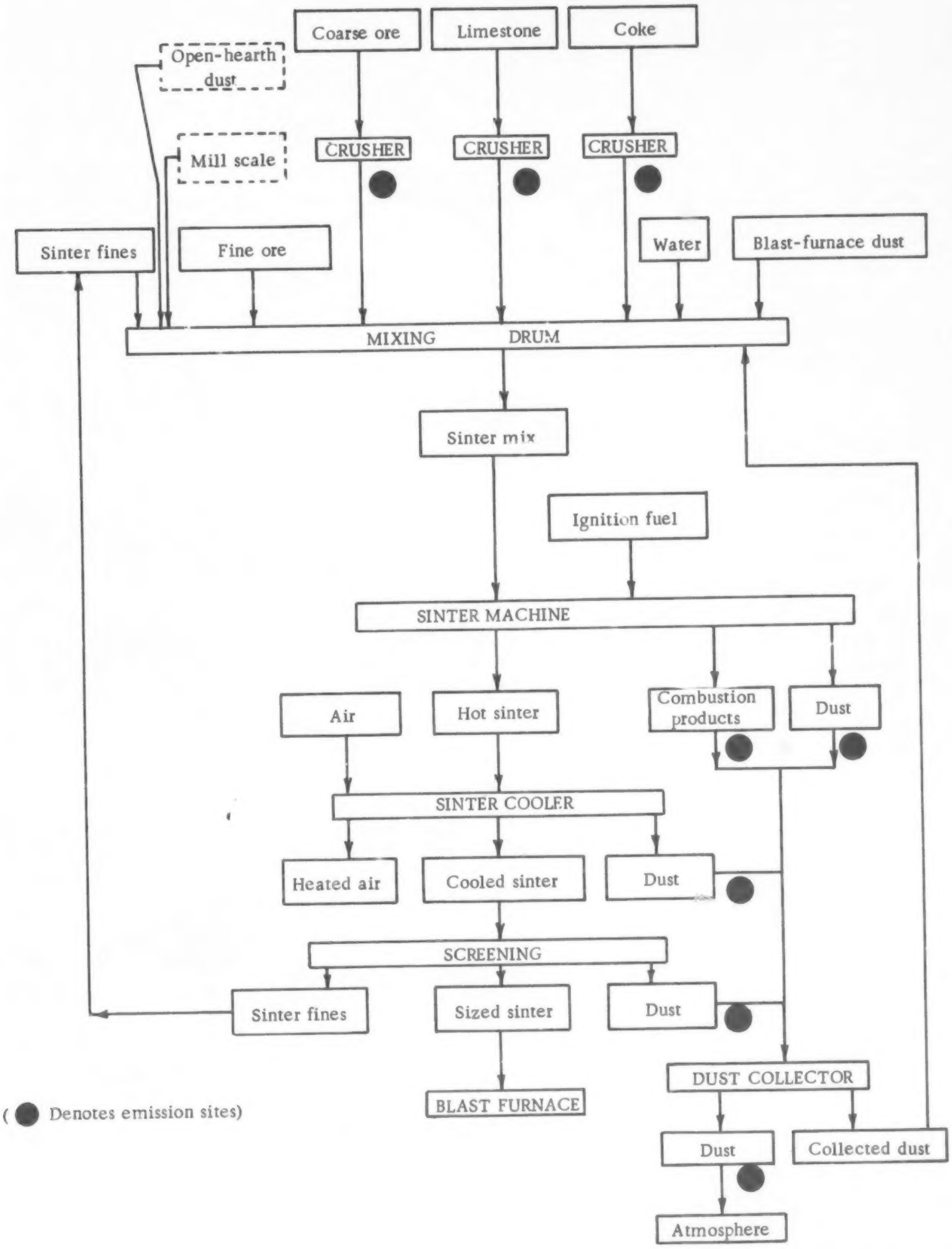

Coarse ore
Limestone
Coke
Open-hearth dust
Mill scale
CRUSHER
CRUSHER
CRUSHER
Sinter fines
Fine ore
Water
Blast-furnace dust
MIXING DRUM
Sinter mix
Ignition fuel
SINTER MACHINE
Air
Hot sinter
Combustion products
Dust
SINTER COOLER
Heated air
Cooled sinter
Dust
SCREENING
Sinter fines
Sized sinter
Dust
DUST COLLECTOR
BLAST FURNACE
Dust
Collected dust
Atmosphere
(● Denotes emission sites)

FIGURE IV-3. TYPICAL FLOW SHEET FOR A SINTERING PLANT

generated in the plant are handled usually by simple cyclones or baghouses. The induration operation (heat hardening) is conducted at relatively low air-flow rates, and formation of particulate emissions usually is not substantial. Although finished pellets are strong and abrasion loss is low, during loading for shipment a considerable amount of dust is released.

Ironmaking

The blast furnace is a massive refractory-lined structure about 100 feet high and up to 30 feet or more in diameter at the hearth. Iron ores, fluxes, and coke (jointly called the burden) are charged at the top of the furnace through a series of seals (called bells). Air preheated in regenerative stoves is forced through ports (called tuyeres) arranged around and just above the hearth. The air (sometimes augmented with oil, gas, oxygen, or steam) reacts immediately with ignited coke to generate hot reducing gases which, in turn, react with the oxygen in the ore to reduce it to iron. As the burden moves downward into the fusion zone, the iron becomes molten and collects in the hearth. Fluxes in the burden react with impurities in the ore and coke and form a layer of molten slag that floats on top of the molten iron. Periodically, the iron is cast into ladle cars that deliver it to the steelmaking furnaces. Slag is tapped from the furnace and transported to a dump area, or is granulated with water. The gas ascending in the blast furnace is removed at the top, stripped of dust, and then used as fuel to fire the regenerative stoves of the blast furnace. It is also used as fuel in the powerhouse and for other operations. Figure IV-4 shows a flow diagram of blast-furnace operations; the circles indicate emission sites.

Charging

Modern blast-furnace burdens consist of sinter, pellets, screened ore, or a mixture of these, plus coke and fluxes. Raw materials are moved from the stockpiles to surge hoppers (called pockets) at the blast furnace. Coke is usually transferred to the pockets by conveyor belt; ore and flux are transferred by bottom-dump cars. Materials drawn from the pockets are weighed and transferred to the top of the blast furnace by a skip hoist. Usually a scale-mounted car is used for the transfer of ore and flux from the pockets to the skips, and a conveyor is used to transfer coke.

The raw materials are dumped from the skips into a receiving hopper at the top of the furnace. In step-wise fashion, the materials are dropped through a series of two or more seals with intermediate hoppers. This seal system minimizes the escape of furnace gases as charges pass successively from the outer hopper to the furnace.

Operations in the stockhouse are dusty, and shrouding at transfer points aids in confining the dust. Conveyor belts raise less dust than transfer cars. The transfer at the top of the furnace is highly exposed, but partial shrouding is possible. Leakage of gases, which also contain particulates, can develop in the bell system as a result of wear or distortion of seals. In high-pressure blast furnaces, a steam system maintains back pressure between closed seals during burden transfer.

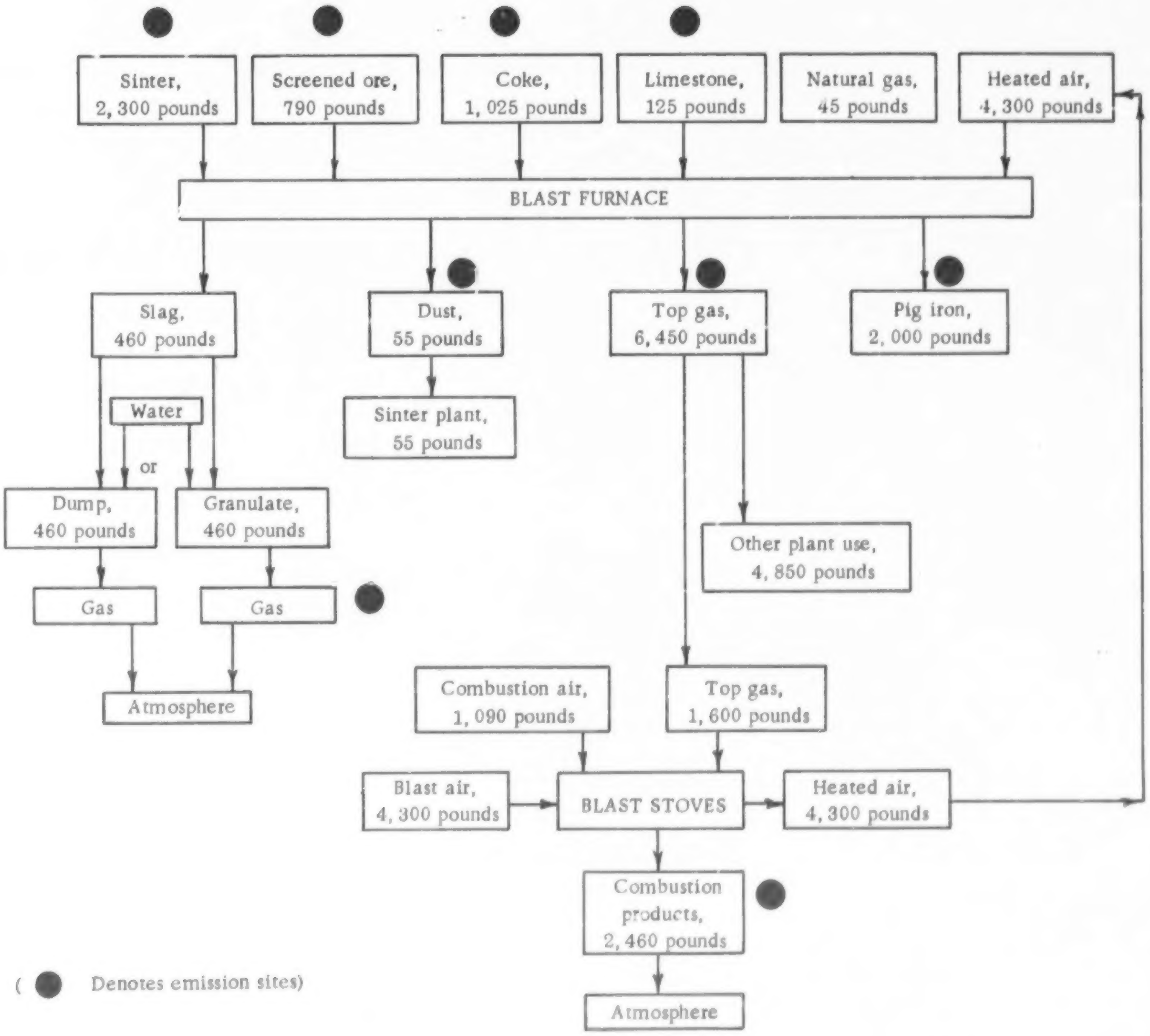

Sinter,
2, 300 pounds
Screened ore,
790 pounds
Coke,
1, 025 pounds
Limestone,
125 pounds
Natural gas,
45 pounds
Heated air,
4, 300 pounds
BLAST FURNACE
Slag,
460 pounds
Dust,
55 pounds
Top gas,
6, 450 pounds
Pig iron,
2, 000 pounds
Water
or
Sinter plant,
55 pounds
Dump,
460 pounds
Granulate,
460 pounds
Other plant use,
4, 850 pounds
Gas
Gas
Atmosphere
Combustion air,
1, 090 pounds
Top gas,
1, 600 pounds
Blast air,
4, 300 pounds
BLAST STOVES
Heated air,
4, 300 pounds
Combustion
products,
2, 460 pounds
Atmosphere
(● Denotes emission sites)

FIGURE IV-4. TYPICAL BLAST-FURNACE OPERATION WITH A BURDEN CONSISTING MAINLY OF SINTER, AND WITH INJECTION OF NATURAL GAS

Smelting

Slips during smelting are sudden movements of the burden in the furnace. In some practices, small, periodic, controlled slips are caused deliberately. Large, uncontrolled slips may generate high pressures that are relieved by bleeders (safety valves) in the uptakes (gas-collection mains) at the top of the furnace. In such cases, relief of the pressure may be accompanied by a discharge of dust and gas into the atmosphere. Improved raw materials have reduced the dust loading in the furnace and have also minimized abnormal operating conditions that cause slips. Control on some blast furnaces has advanced to the stage where bleeders open rarely and only for short intervals.

The raw blast-furnace gas consists chiefly of steam, nitrogen, hydrogen, carbon monoxide, and carbon dioxide. The carbon monoxide content is about 25 to 30 percent. The hydrogen content ranges from 1 to 6 percent and varies with blast moisture and fuel injection. At least some of the gas discharges continuously through leaks at the bells and in areas where the furnace shell is pierced for instruments and coolers.

Dust entrained in the blast-furnace gas results from abrasion of the burden during charging and during the early stages of passage down the blast furnace.

The flue gas leaving the blast furnace is dusty, and is cleaned to a concentration of less than 0.01 grain/scf to assure that clogging or slagging reactions do not occur when the gas is used as a fuel to fire the regenerative blast stoves. About 30 percent of the gas usually is used to heat the stoves; the rest is used as fuel for other in-plant heating purposes, or flared. Commonly a gas-cleaning system will include a dust catcher and a primary washer. Additional equipment is used only as dictated by the in-plant use of the gas.

Casting and Flushing

Blast-furnace iron is saturated with carbon. As soon as it emerges from the furnace, graphite flakes are rejected and rise to the surface where air currents sweep them into the atmosphere. Manganese vapor is also given off and oxidizes to form a fine dust, but the amount is quite small. The graphite "kish" is a nuisance because it is readily windblown and is difficult to remove after it has settled. Kish control during casting consists of running the iron short distances to minimize the amount that can form and escape before the iron flows into closed ladles.

The volume of slag from the blast furnace is similar to the volume of hot metal. Slag is flushed out of the furnace prior to and during each cast of iron. The sulfur load in the slag is 6.5 to 9.5 pounds per ton of hot metal. During flushing, some of the sulfur may react with oxygen and moisture in the air to form sulfurous gases near the slag runners. Long runners at older furnaces give greater surface exposure and increased fouling of the air. Most slags are transported in open ladles to dump areas where hydrogen sulfide is evolved as the slag cools and weathers. In some newer practices, the slag runs a short distance and is granulated with high-pressure water. However, the formation of hydrogen sulfide may continue in the granulation pit at low temperature.

A small portion of the molten iron from American blast furnaces is solidified into solid "pigs" for distribution. The kish problem discussed above is severe during pigging.

Steelmaking

Open-Hearth Furnaces

With the growth of other steelmaking processes, the percentage of steel made in open-hearth furnaces has decreased, but 55 percent of U. S. raw steel was made by this process in 1967. Open-hearth furnaces range in holding capacity from 25 to 600 tons. Time to produce a heat ranges normally from 8 to 12 hours, but this time can be shortened by lancing the bath with oxygen.

Special charging machines charge iron ore, limestone, scrap iron, and scrap steel to the open hearth at the start of a heat. An intense flame from combustion of oil, tar, coke-oven gas, or natural gas travels the length of the furnace to heat the solid charge. The hot waste gases are led through regenerative chambers called checkers, and the flow of the flame is reversed each 15 to 20 minutes to let the newly heated set of checkers preheat the combustion air. Hot metal from the blast furnace is added by pouring from a large ladle into a spout set temporarily in a door of the open-hearth furnace. Carbon and impurities are oxidized from the bath to convert the charge into steel. After the heat is refined to the desired composition, the molten steel is ready for deoxidation and tapping. The tap hole is at the base of one wall and discharges into a ladle. To shorten the time of open-hearth heats, oxygen may be injected into the bath by lances extending through the roof of the furnace. Oxygen consumption may range from 600 to 1000 cubic feet per ton of steel. A flow sheet for a typical hot-metal operating practice is shown in Figure IV-5. The circles indicate points of emission.

Emissions. Minor emissions of iron oxide occur during the charging and tapping of open-hearth furnaces, but the main emissions are in the combustion gases. Particulates in the combustion product consist of red iron oxide and magnetic iron oxide. The gas also contains sulfur compounds and fly ash from the use of fuels such as oil, tar, and coke-oven gas. Firing with oil is reported to create a lower average dust loading than firing with tar.

The amount of dust generated varies at different stages of the steelmaking process and with the particular practice. Typical dust loadings for oxygen-lanced open-hearth furnaces are estimated to be 20 to 30 pounds per net ton of raw steel. Without oxygen lancing, about 8 to 10 pounds of dust per net ton of steel is emitted.

The slag pockets, checker chambers, and flues to waste-heat boilers provide opportunities for settling-out of dust from the combustion gases, and thus served as fairly efficient dust collectors until the advent of oxygen lancing. The use of oxygen lancing in open hearths increases the dust loading and generates large volumes of metallurgical fume. Effective control of the emissions is obtained with electrostatic precipitators. Venturi scrubbers and baghouses are also being used. Illustrative flow diagrams of open-hearth dust-collecting systems are presented in Figure IV-6.

Teeming. Teeming is the pouring of liquid steel into cast iron molds where the steel solidifies into ingots. In the teeming area, ingot molds on a string of cars are filled with steel from the ladle. In 1967, about 94 percent of raw steel produced in the

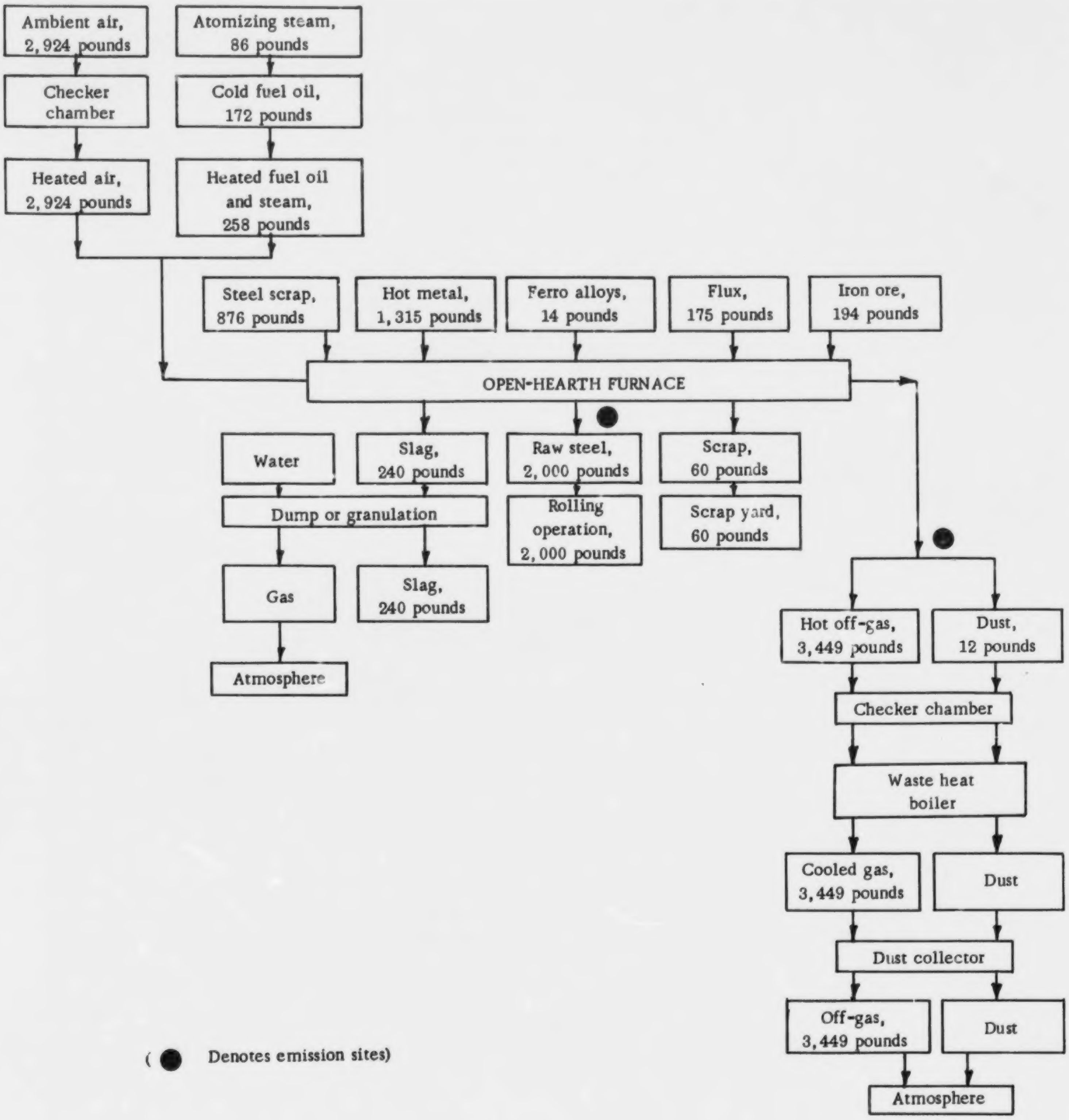
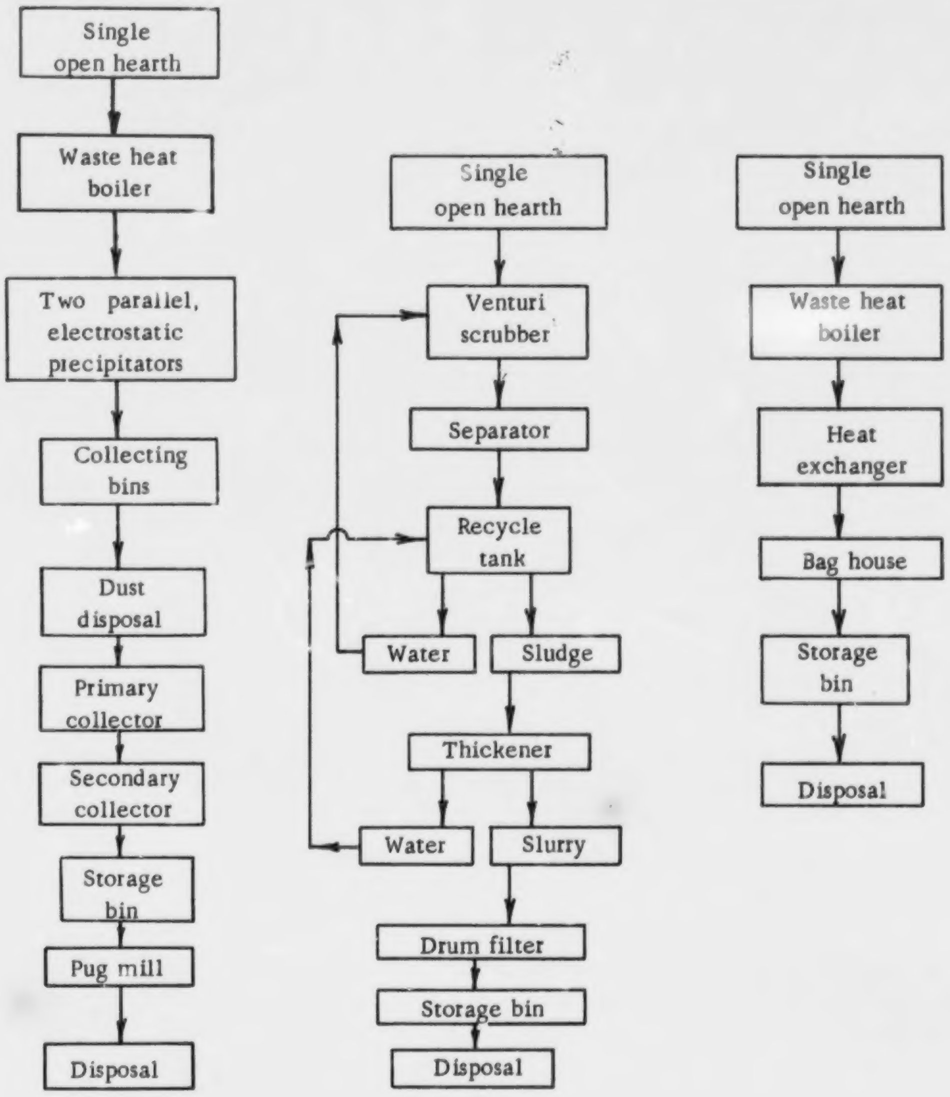

Ambient air, 2,924 pounds
Atomizing steam, 86 pounds
Checker chamber
Cold fuel oil, 172 pounds
Heated air, 2,924 pounds
Heated fuel oil and steam, 258 pounds
Steel scrap, 876 pounds
Hot metal, 1,315 pounds
Ferro alloys, 14 pounds
Flux, 175 pounds
Iron ore, 194 pounds
OPEN-HEARTH FURNACE
Water
Slag, 240 pounds
Raw steel, 2,000 pounds
Scrap, 60 pounds
Dump or granulation
Rolling operation, 2,000 pounds
Scrap yard, 60 pounds
Gas
Slag, 240 pounds
Atmosphere
Hot off-gas, 3,449 pounds
Dust, 12 pounds
Checker chamber
Waste heat boiler
Cooled gas, 3,449 pounds
Dust
Dust collector
Off-gas, 3,449 pounds
Dust
Atmosphere
(● Denotes emission sites)

FIGURE IV-5. OPEN-HEARTH FURNACE OPERATING WITH HOT-METAL PRACTICE CONSISTING OF 60 PERCENT HOT METAL AND 40 PERCENT STEEL SCRAP (ORE PRACTICE)


Single open hearth
Waste heat boiler
Two parallel, electrostatic precipitators
Collecting bins
Dust disposal
Primary collector
Secondary collector
Storage bin
Pug mill
Disposal
Single open hearth
Venturi scrubber
Separator
Recycle tank
Water
Sludge
Thickener
Water
Slurry
Drum filter
Storage bin
Disposal
Single open hearth
Waste heat boiler
Heat exchanger
Bag house
Storage bin
Disposal

U. S. Steel Corp.
Fairless, Pa. - 1953

Republic Steel Corp.
Buffalo District - 1964

Bethlehem Steel Corp.
Sparrows Pt., Md. - 1963

FIGURE IV-6. ILLUSTRATIVE FLOW DIAGRAMS OF OPEN-HEARTH DUST-COLLECTING SYSTEMS

United States was poured into ingot molds. The use of tar and bitumens as mold coatings has been curtailed in the past decade, with a resulting decrease in the amount of visible emission during teeming. However, with some present teeming practices, visibility can become highly restricted at the teeming station. Little information is available on methods of controlling the teeming emissions.

Basic Oxygen Furnaces

It is estimated that by 1970 nearly half of the steel in the United States will be made by the basic-oxygen-furnace (BOF) process. The furnace is a pear-shaped shell lined with refractory brick. It is charged through the top, and tilted down for tapping. Typically, the charge consists of 70 percent blast-furnace hot metal and 30 percent scrap, plus fluxes. A water-cooled lance impinges oxygen at high velocity on the surface of the charge to promote agitation mixing of the oxygen with the molten bath. Rapid oxidation of carbon, silicon, manganese, and some of the iron occurs. These exothermic reactions supply heat to melt the scrap and reach the tapping temperature. Some impurities from the charge enter the slag. A typical 150-ton BOF can produce a heat in about 33 minutes.

A flow sheet for a typical BOF process is presented in Figure IV-7. Points of major emissions are indicated by the circles.

Emissions. Kish is formed during the charging of hot metal. It consists of flakes of graphite, and may include fragments of iron oxide and traces of quartz and calcite.

During the blow with oxygen, the predominant particulate emission is fine iron oxide fume. If galvanized scrap is part of the charge, zinc oxide in the collected dust makes the dust unsuitable for sintering for feed to the blast furnace. For this reason, the trend is to divert galvanized scrap to open hearths.

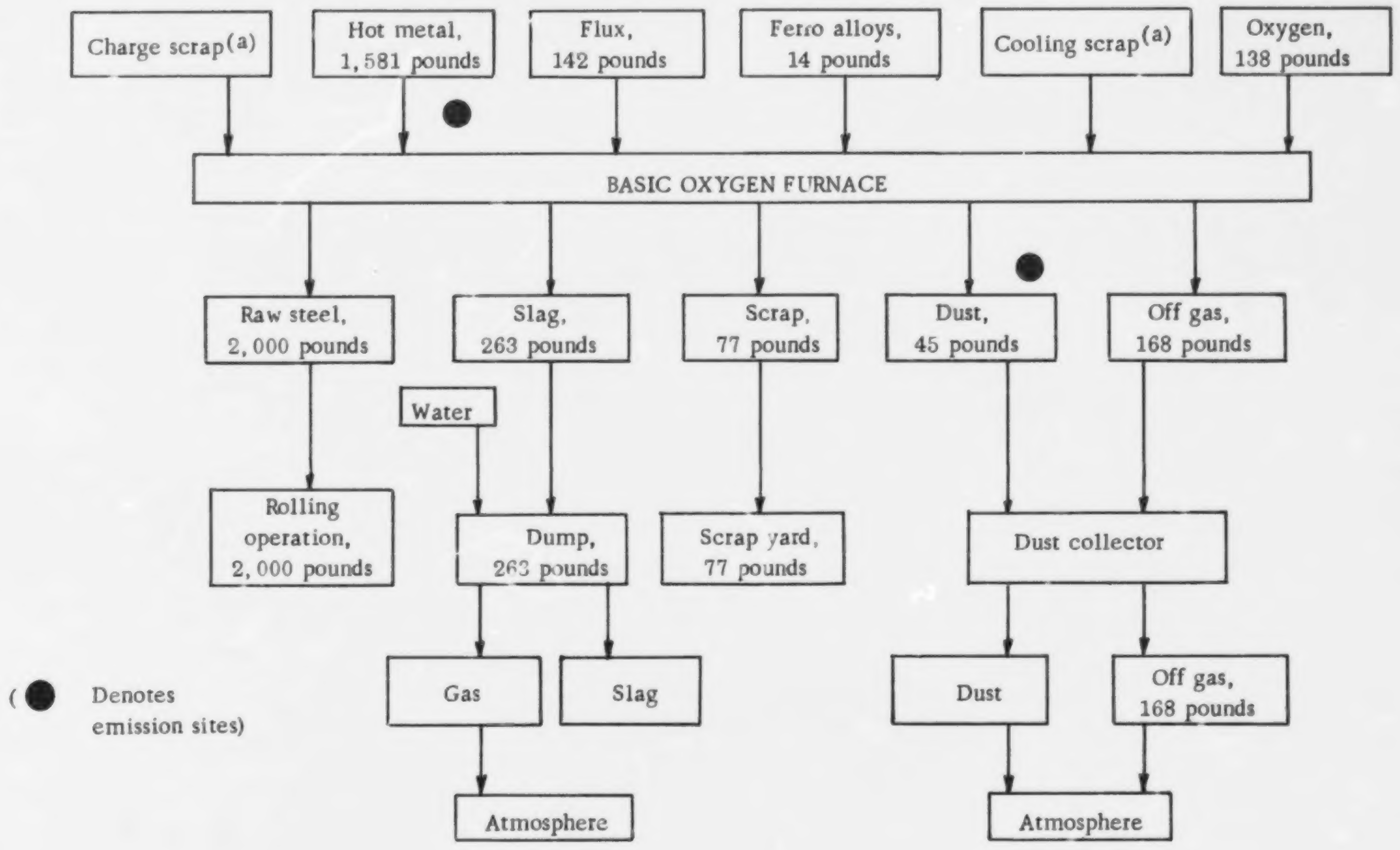
The amount of dust per net ton of raw BOF steel ranges from 20 to 50 pounds. In 1968, an average of 40 pounds per ton was reported by one plant.

Flow diagrams for typical gas-cleaning systems for the BOF are shown in Figure IV-8. Serious air pollution is avoided by the use of these cleaning systems.

Teeming of BOF heats is the same as was described for open-hearth heats.

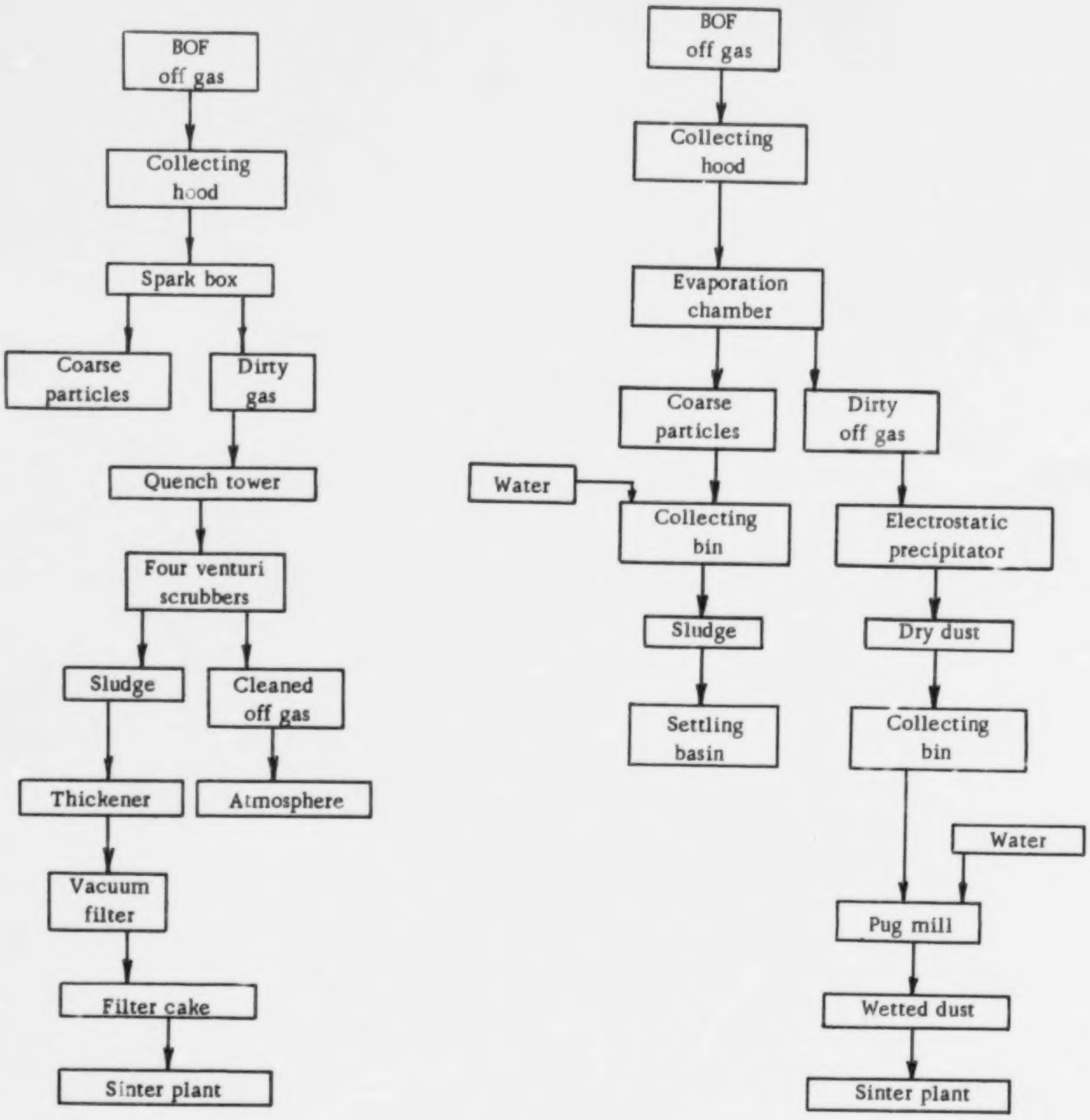
Electric-Arc Furnaces

In 1967, electric-arc furnaces produced about 11 percent of the total raw carbon steel made in the United States and 36 percent of the alloy and stainless steels. About 59 percent of all electric-furnace heats were carbon steels. Electric-arc furnaces are refractory-lined cylindrical basins having a capacity of up to 200 tons or more. In 1968, 40 percent held less than 50 tons, 36 percent held from 50 to 90 tons, and 24 percent were over 90 tons in holding capacity.


Charge scrap(a)
Hot metal, 1,581 pounds
Flux, 142 pounds
Ferro alloys, 14 pounds
Cooling scrap(a)
Oxygen, 138 pounds
BASIC OXYGEN FURNACE
Raw steel, 2,000 pounds
Slag, 263 pounds
Scrap, 77 pounds
Dust, 45 pounds
Off gas, 168 pounds
Water
Rolling operation, 2,000 pounds
Dump, 263 pounds
Scrap yard, 77 pounds
Dust collector
Gas
Slag
Dust
Off gas, 168 pounds
Atmosphere
Atmosphere
(● Denotes emission sites)

(a) Charge scrap plus cooling scrap = 678 pounds.

FIGURE IV-7. BASIC OXYGEN FURNACE OPERATING WITH 70 PERCENT HOT METAL AND 30 PERCENT STEEL SCRAP


BOF off gas
Collecting hood
Spark box
Coarse particles
Dirty gas
Quench tower
Four venturi scrubbers
Sludge
Cleaned off gas
Thickener
Atmosphere
Vacuum filter
Filter cake
Sinter plant
BOF off gas
Collecting hood
Evaporation chamber
Coarse particles
Dirty off gas
Water
Collecting bin
Electrostatic precipitator
Sludge
Dry dust
Settling basin
Collecting bin
Water
Pug mill
Wetted dust
Sinter plant

Inland Steel Company
Indiana Harbor, Ind. - 1965

Wisconsin Steel
South Chicago Ill. - 1964

FIGURE IV-8. EXAMPLES OF GAS-CLEANING SYSTEMS FOR BOF STEELMAKING FURNACES

High-amperage electricity at moderate voltage is passed through large graphite electrodes extending down through the roof of the furnace. The charge consists of selected steel scrap plus fluxes and alloying elements to achieve the desired composition. Melting is accomplished by the heat of the arc formed between the electrodes and the charge.

Emissions. Preheating of the scrap is not yet a common practice for shortening the heat time. Where preheating is practiced, it is done most commonly with air-fuel burners. Oxy-fuel burners are used to only a limited extent. The scrap is rarely heated to above 1800 F; thus preheating creates no significant emission problems unless dirty fuels are used or combustible dirt (such as oil or rubber) is in the scrap.

Electric-induction furnaces melt special alloys on a small scale. If the charge is free of tramp combustibles, emission from these furnaces is minor and is collected readily in simple equipment.

Emissions in the electric-arc furnace can originate from light scrap that oxidizes readily, from dirty scrap (a major source), and from oxygen lancing. A flow sheet for a typical electric-arc furnace process is shown in Figure IV-9. The main emissions are fumes from scrap preheating, iron oxide dust from the melting operations, and furnace off-gases.

The amount of dust released per net ton of electric-furnace steel depends on the condition of the scrap and whether or not oxygen lancing is used. Dirty scrap can raise the dust emissions from a normal level of 8 to 15 pounds to as high as 40 pounds per net ton of steel. It has been estimated that oxygen lancing produces 20 percent of the total emissions. The composition of the off-gas from the electric furnace varies with the practice. The chief constituents are carbon monoxide, carbon dioxide, nitrogen, and oxygen.

Emissions leave the furnace through the electrode ports in the furnace roof, out of the tapping spout and slagging door and, in the case of top-charged furnaces, through the open furnace top during charging. Three main types of systems are used to collect the emissions: (1) hoods over and around the furnace, (2) direct extraction under draft from inside the furnace, and (3) shop-roof hoods.

In the first type of system, hoods are fitted at the points of emission, and ducts pass the emissions to the dust collector. Hoods of this type must be movable when used with top-charging furnaces. They tend to obscure visibility from the crane operator's cab. Warpage of the hoods is a problem, and they seldom last 1 year.

Direct extraction by drafted duct from inside the furnace causes shop air to flow into the furnace and thus minimizes the discharge of emissions through the doors and ports. This system increases roof life and may decrease electrode consumption. It affects recovery of alloying elements in the steel bath, and may create some difficulties with carbide slags used in refining of special steels. Heat exchangers must be used unless the duct length is adequate to cool the gases by radiation to a safe entry temperature into the dust collector.

In the shop-roof extraction system, the shop building serves as the collector hood. Ducts in the roof of the building exhaust the emissions to the dust-collecting system.

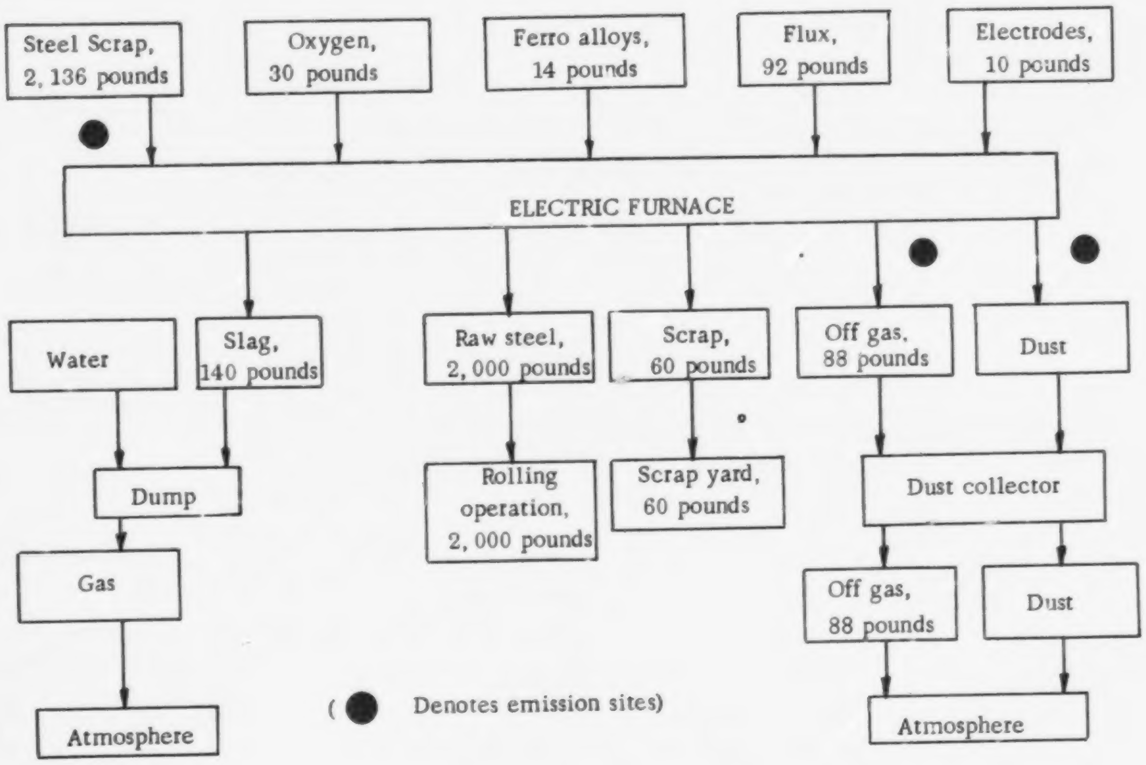

Steel Scrap, 2,136 pounds
Oxygen, 30 pounds
Ferro alloys, 14 pounds
Flux, 92 pounds
Electrodes, 10 pounds
ELECTRIC FURNACE
Water
Slag, 140 pounds
Raw steel, 2,000 pounds
Scrap, 60 pounds
Off gas, 88 pounds
Dust
Dump
Rolling operation, 2,000 pounds
Scrap yard, 60 pounds
Dust collector
Gas
Off gas, 88 pounds
Dust
Atmosphere
(● Denotes emission sites)
Atmosphere

FIGURE IV-9. EXAMPLE OF ELECTRIC-FURNACE STEELMAKING PRACTICE

Teeming practice is the same as for open hearth and BOF heats. Some electric-furnace shops use roof-extraction exhaust systems in the teeming building to collect the fumes.

Flow diagrams of dust-collecting systems that use baghouses or wet scrubbers for direct extraction and for hood extraction are presented in Figures IV-10 and IV-11. Figure IV-12 is the flow diagram for emission control by a shop-roof extraction system.

Vacuum Degassing of Steel

For certain critical applications, steel is degassed by vacuum treatment. Three methods are used: (1) stream degassing, (2) circulation degassing, and (3) ladle degassing.

The source of emissions in vacuum degassing is the molten steel in the vacuum chamber. The principal gases emitted are carbon dioxide, carbon monoxide, and hydrogen. The violent agitation of the molten steel and the vaporization of some metallics generates dust.

The steam ejectors used to create the degassing vacuum also serve as scrubbers. Thus, dusts are normally not released to the atmosphere. One source of information states that about 10 pounds of dust are collected in degassing 100 tons of steel.

Continuous Casting of Steel

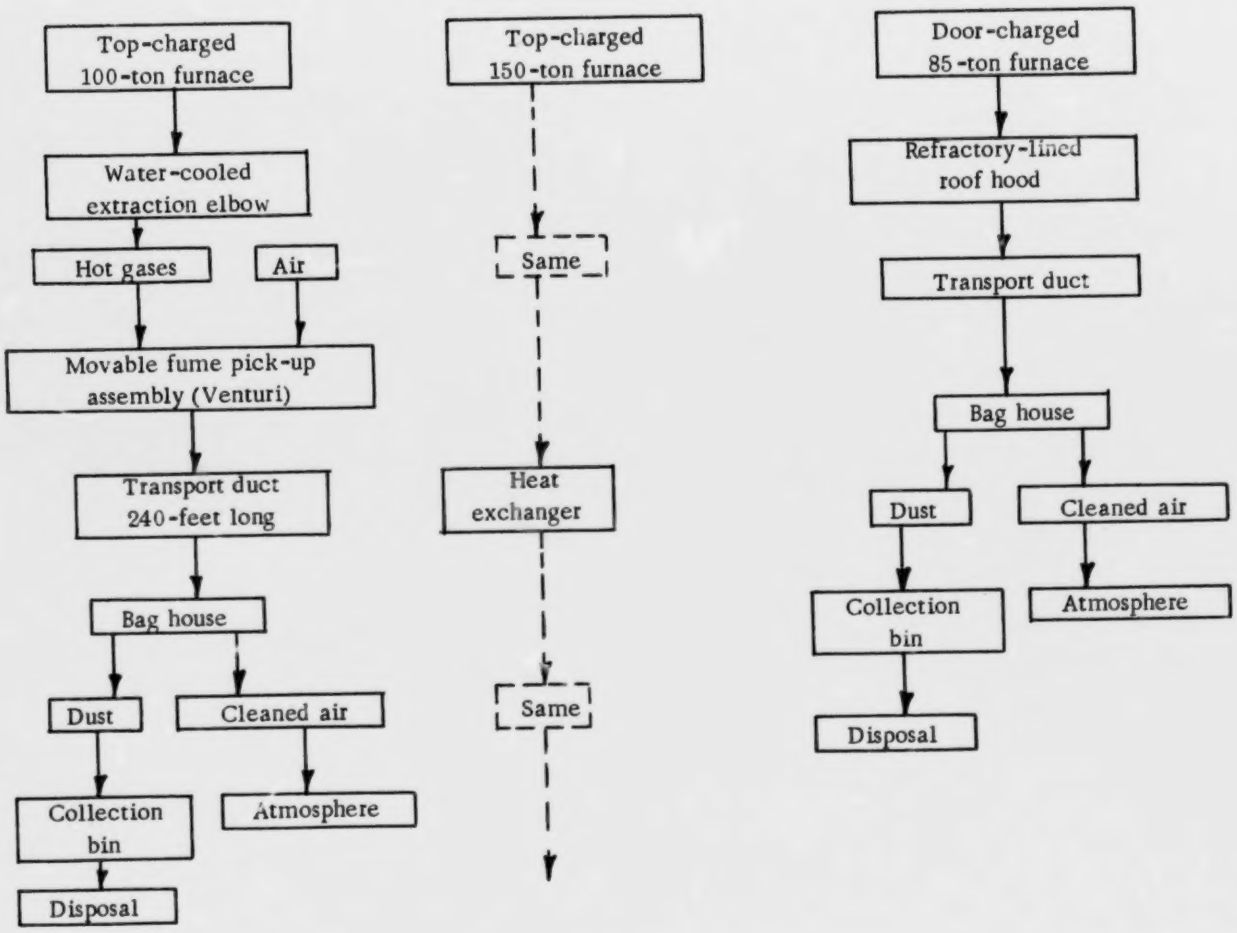
Continuous casting is an alternative to conventional teeming into ingot molds. In continuous casting, molten steel is poured into a water-cooled, bottomless copper mold and cools quickly to the shape of the mold, from which it is withdrawn continuously. The estimated continuous casting capacity in the United States in 1968 was about 7 million net tons per year, and is expected to double in 1969.

Emissions during continuous casting are markedly lower than during teeming into ingot molds, because the rapeseed oil used as a mold coating creates only a small amount of fume. Continuous casting is conducted in one location rather than over a large area. This permits the use of a localized fume-collecting system. The pouring tundish may be blanketed with a reducing gas to minimize oxidation of the steel, and for vacuum-degassed heats the stream from the tundish to the mold is shrouded with argon.

Steel Shaping

Primary Breakdown

Soaking pits are reheat furnaces in which steel ingots are brought to a controlled temperature for rolling. They are fired with blast-furnace gas, coke-oven gas, or a mixture. The amounts of particulate emissions are small, but gaseous emissions may include sulfur dioxide if the coke-oven gas has not been freed of hydrogen sulfide. No

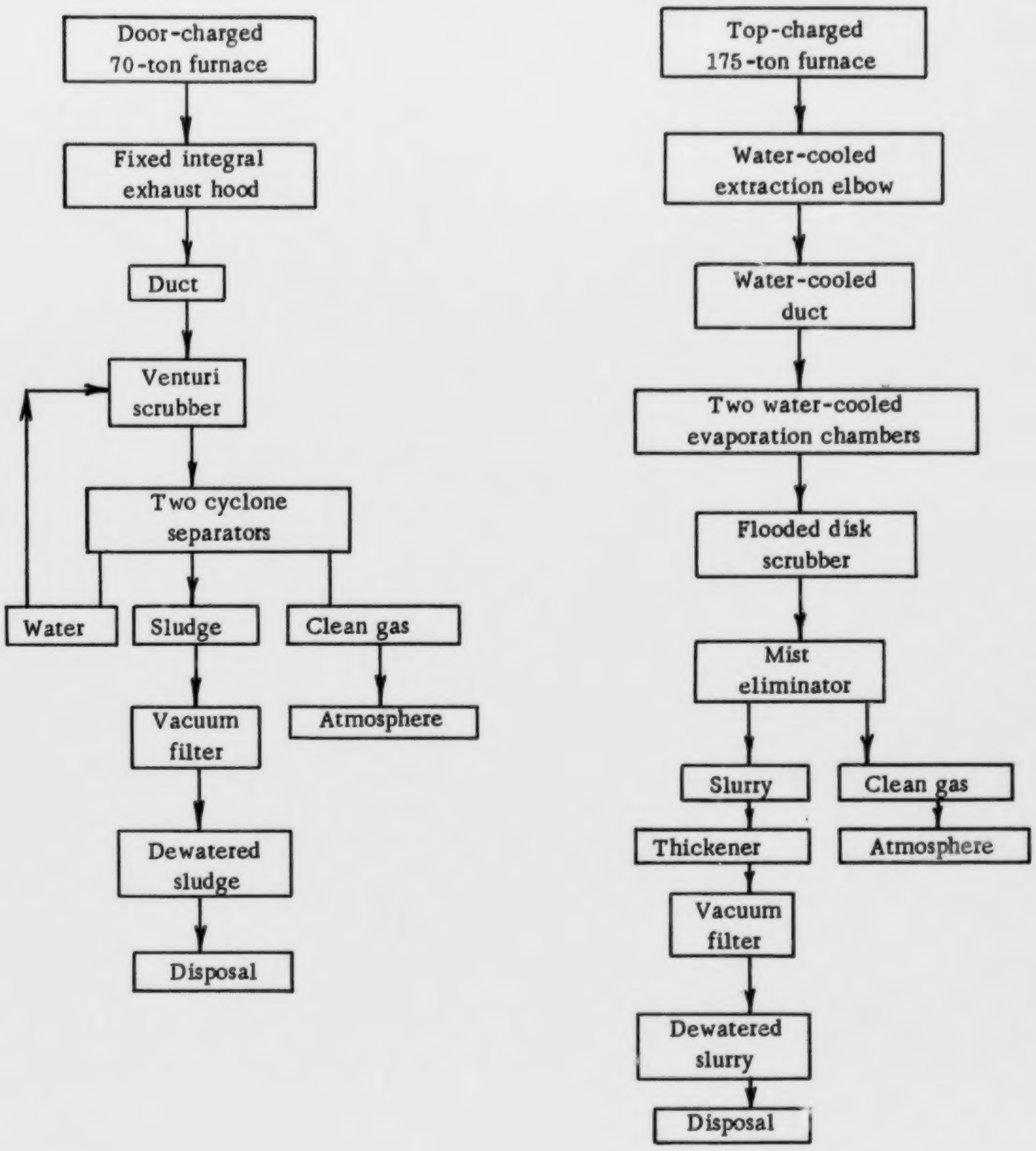

Top-charged
100-ton furnace
Water-cooled
extraction elbow
Hot gases
Air
Movable fume pick-up
assembly (Venturi)
Transport duct
240-feet long
Bag house
Dust
Cleaned air
Collection
bin
Atmosphere
Disposal
Top-charged
150-ton furnace
Same
Heat
exchanger
Same
Door-charged
85-ton furnace
Refractory-lined
roof hood
Transport duct
Bag house
Dust
Cleaned air
Collection
bin
Atmosphere
Disposal

Lukens Steel Co.
Coatesville, Pa. - 1964

Lukens Steel Co.
Coatesville, Pa. - 1966

U. S. Steel Corp.
Chicago, Ill. - 1961

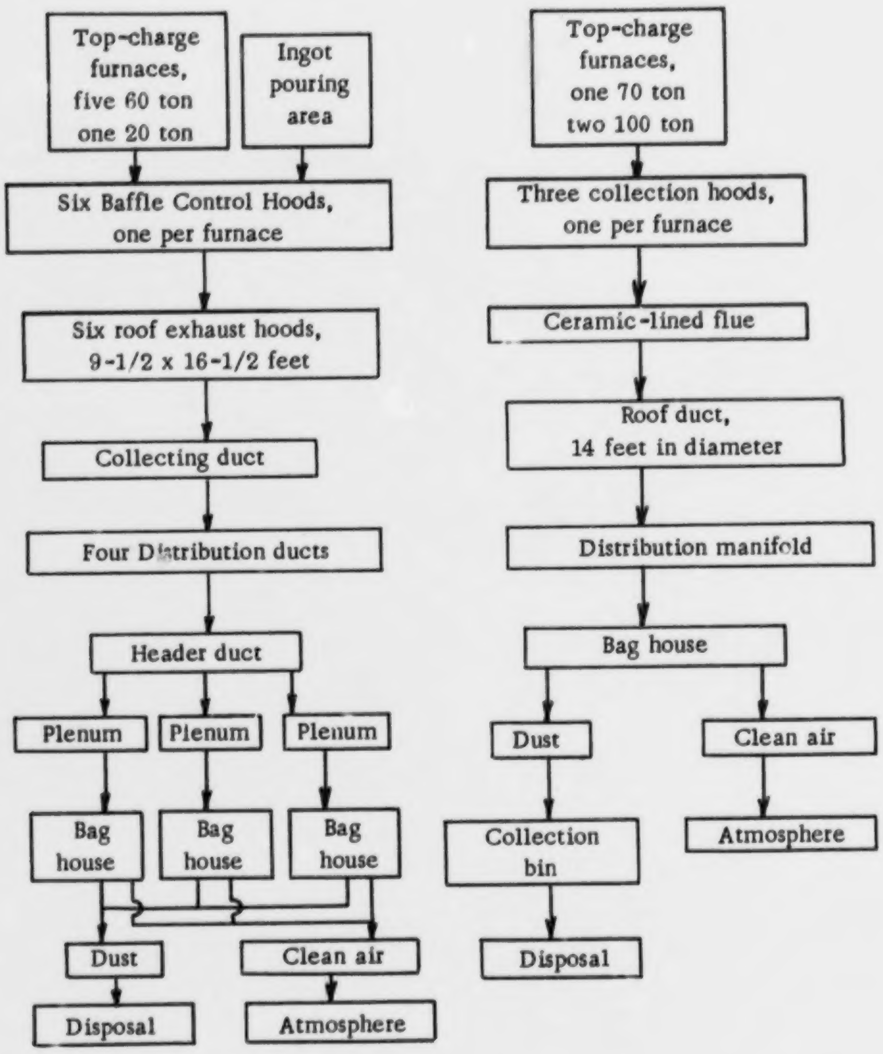
FIGURE IV-10. EXAMPLES OF ELECTRIC-FURNACE DIRECT-EXTRACTION EMISSION-CONTROL SYSTEMS WITH BAGHOUSES


Door-charged 70-ton furnace
Fixed integral exhaust hood
Duct
Venturi scrubber
Two cyclone separators
Water
Sludge
Clean gas
Vacuum filter
Atmosphere
Dewatered sludge
Disposal
Top-charged 175-ton furnace
Water-cooled extraction elbow
Water-cooled duct
Two water-cooled evaporation chambers
Flooded disk scrubber
Mist eliminator
Slurry
Clean gas
Thickener
Atmosphere
Vacuum filter
Dewatered slurry
Disposal

Armco Steel Corp.
Butler, Pa. - 1959

Armco Steel Corp.
Houston, Texas - 1966

FIGURE IV-11. EXAMPLES OF ELECTRIC-FURNACE DUST-COLLECTING SYSTEMS USING WET SCRUBBERS


Top-charge furnaces, five 60 ton one 20 ton
Ingot pouring area
Six Baffle Control Hoods, one per furnace
Six roof exhaust hoods, 9-1/2 x 16-1/2 feet
Collecting duct
Four Distribution ducts
Header duct
Plenum
Plenum
Plenum
Bag house
Bag house
Bag house
Dust
Clean air
Disposal
Atmosphere
Top-charge furnaces, one 70 ton two 100 ton
Three collection hoods, one per furnace
Ceramic-lined flue
Roof duct, 14 feet in diameter
Distribution manifold
Bag house
Dust
Clean air
Collection bin
Atmosphere
Disposal

Jones & Laughlin Steel Corp.
Warren, Mich. - 1966

Bethlehem Steel Corp.
Los Angeles, Cal. - 1966

FIGURE IV-12. EXAMPLES OF ELECTRIC-FURNACE SHOP-ROOF EMISSION-CONTROL SYSTEMS

economical commercial method is available for removal of the sulfur dioxide in the exhaust gases.

During breakdown of the ingots by rolling into billets, blooms, or slabs, the major emission is steam; emission of dust is minor.

Conditioning, Reheating, and Hot Rolling

After ingots are rolled to billets, blooms, or slabs, they may be cooled, inspected, and conditioned by grinding, chipping, or scarfing surface defects with hand torches. More complete surface conditioning is sometimes obtained via all-over scarfing with oxygen in special scarfing machines. Then the steel slabs and billets are reheated before they enter the hot-strip mill.

The fine particulates generated during grinding are airborne only a short distance in the area. Sometimes they are collected at the grinding station. Billet scarfing causes a metal loss ranging from 3 to 6 percent, but most of the loss is spatter – not fume. No emission controls are used in hand scarfing, except that hoods are sometimes used if the shop practice calls for extensive hand scarfing. The loss in machine scarfing of slabs is up to 2.5 percent, and up to 7 percent for blooms. The emissions are chiefly iron oxides and are collected with electrostatic precipitators or high-energy scrubbers. Machine scarfing would result in serious air pollution if control systems were not used.

Emissions during reheating are mixtures of carbon monoxide, carbon dioxide, and nitrogen from the combustion of natural gas. Emissions at the mills consist mostly of steam, which is confined to the area of the mills. The emission of fine iron oxides at strip finishing stands is considered to be significant enough that some mills collect these emissions with high-energy scrubbers.

Except for scarfing operations, no serious emission problem exists in the operations of conditioning, reheating, and hot rolling. This conclusion also applies to hot-forging and hot-forming operations.

Acid Pickling

Acid treatment, called pickling, is used to clean the oxidized surface of hot-rolled steel in preparation for cold rolling. Either hydrochloric or sulfuric acid is used. Acid fumes are the chief emissions during pickling. Hoods exhaust these fumes to a wet scrubber and thence to a packed tower. One source states the collection rate is about 100 grains of hydrochloric acid per ton of steel. For pickling of low tonnages of steel, the fume system may be too costly, and the fumes are then ejected to the atmosphere through a roof exhaust.

Pickling can contribute moderately to air pollution if control systems are not used.

Cold Rolling and Cold Forming

In high-speed cold rolling, a water-oil mist is generated from the emulsion lubricant applied to the rolls. Collection of this emission is by mechanical mist eliminators or wet scrubbers. Neither cold-rolling nor cold-forming operations contribute significantly to air pollution.

Steel Finishing

Continuous strip lines lend themselves to convenient control of emissions during coating operations. Coatings include zinc, tin, terne (lead alloy), aluminum, chromium, nickel, copper, phosphate, and a variety of paints. Prior to coating, the strip is heated to carbonize grease or oil films, and the lightly oxidized surface is cleaned in an acid tank or by the action of a reducing atmosphere in a furnace. A hot alkaline solution may be used instead of heat to remove the grease film before pickling.

In dip coating (zinc, aluminum, and terne coat), the preheated strip passes through a flux layer on top of the metal bath. In electrolytic processes (zinc, chromium, nickel, and copper), the cleaned strip enters directly into the plating bath. Recent processes for coating with chromium and nickel involve coating with chemicals which are then reduced to metal in a hydrogen atmosphere. Phosphate coatings are produced by dipping steel in a dilute acid phosphate solution saturated with a metal such as zinc, cadmium, aluminum, or lead. The metal surface is converted to an insoluble crystalline phosphate coating. Paints are applied to cleaned strip by an electrophoretic process, by dipping, or by roller coating. Painting operations emit solvent vapors which can be collected by an exhaust system that disperses the vapors to the atmosphere outside of building. During baking, the evolved vapors are combusted or exhausted.

In these finishing operations, emission of particulates is negligible. Heating of the steel results in stack gases having the normal carbon monoxide-carbon dioxide mixture from combustion of natural gas. Acid mists from pickling and vapors from electroplating baths are readily collected by hoods and removed in wet scrubbers and packed towers.

Miscellaneous Operations

Gas Distribution

Blast-furnace gas and coke-oven gas are used as in-plant fuels. Blast-furnace gas has a heat value of about 80 Btu/scf. It is cleaned of particulates to a high degree to make it suitable for heating the blast stoves. Excess blast-furnace gas is used in the powerhouse, for underfiring of coke ovens, and in soaking pits of reheating furnaces. Because its caloric value is low, it is often enriched with natural gas or coke-oven gas.

Coke-oven gas has a heat value of 500 to 550 Btu/scf. It is often used for underfiring coke ovens. The remainder is used for (1) ignition of the bed in sintering plants, (2) injection into the blast furnaces, (3) open-hearth fuel, (4) enrichment of blast-furnace gas, and (5) powerhouse fuel. If the coke-oven gas is not stripped of its hydrogen sulfide, its use as a general fuel results in the release of objectionable sulfur oxides in the products of combustion. The one exception is its use as an auxiliary fuel by injection in the blast furnace. In this case the sulfur goes into the slag. The technology exists for desulfurizing coke-oven gas, and some coke plants are equipped to do it. However, the removal and recovery of sulfur as elemental sulfur, sulfuric acid, or ammonium sulfate is not economically practical.

In the various processes where coke-oven gas is used as a fuel (other than in the blast furnace), the products of combustion will contain sulfur as oxides. The amount of sulfur will depend on the proportion of coke-oven gas making up the fuel. Coking of a low-sulfur coal results in about 3.8 grains of hydrogen sulfide per standard cubic foot of coke-oven gas. If used undiluted, this gas would yield an appreciable amount of sulfur dioxide upon combustion. Coke-oven gas containing up to 0.9 grain of hydrogen sulfide per standard cubic foot is considered to be metallurgically acceptable for general mill use. Usually no control is used on the sulfur oxide emissions when hydrogen sulfide-bearing coke-oven gas is used as a fuel.

Powerhouse

The powerhouse raises steam used for compressing air for the blast furnace, generating electricity, distilling coke by-products, pumping coke-oven and blast-furnace gases, powering of forges and presses, warming residual oil and tar lines, and for comfort heating and general utilities.

Almost any available fuel can be burned in the boiler station. The principal fuel is blast-furnace gas, and the need for additional fuel is balanced out chiefly with non-coking coals having typically 2 percent sulfur. Coke-oven gas and coke breeze are used if there is a surplus.

Blast-furnace gas is a clean fuel; but coal, coke-oven gas, tar, oil, and coke breeze generate sulfur oxides and perhaps some fly ash upon combustion. Methods for economical treatment of flue gases for the removal of sulfur are still under development. If treatment of the flue gases becomes mandatory, it may become economical for mills to diminish steam-raising to the minimum.

With automatic combustion control of gaseous fuels in the boilers, generation of particulates is insignificant and the stack gas is not cleaned. Electrostatic precipitators are used to collect particulate emissions (smoke and fly ash) from firing with other fuels. Except for the exhausting of sulfur oxides to the atmosphere when firing with sulfur-bearing fuels, emission-control systems are effective in preventing pollution of the air.

Plant Waste Incineration

Open-dump burning of steelworks' waste and refuse can create considerable smoke. One mill reports the recent installation of a double-fired incinerator designed to burn all combustible materials cleanly. A fan draws the off-gases through a wet scrubber designed to reduce the stack emissions.

Priorities, Problems, and Opportunities in Pollution-Control Technology

The foregoing review has shown that there are numerous occasions and sites of possible air-polluting emissions within an integrated steelworks. Because of these multiple sources, air-pollution control for steelmakers is a complex and substantial problem. Whereas the public (including the steelmakers) has a single overall objective (cleaner air), this objective is fragmented into dozens of separate pollution-control goals within the plants. To obtain suitable overall progress at feasible rates of investment and of technical development, it is important to assign priorities, to anticipate major problems well in advance, and to identify all possible opportunities for technical gain.

Priorities

In discussing the overall problem of steelworks air pollution, highest priority should be given to control of coke-plant emissions. In particular, primary concern should be directed to emissions of coal smoke and aromatic gases during charging of coal, early stages of coking, and pushing of the finished coke. Imperfect controls at these critical points allow the release of dirty and noxious substances not unlike those released by unregulated burning of soft coal in our cities decades ago. Considerable research and development effort has been expended on control of coking emissions, but unfortunately without satisfactory results to date.

Assignment of lower priorities (by both steelmakers and the public) tends to be based upon the apparent amounts of material emitted from various operations. Because they are visible, particulates have received the most attention until recently. Visible airborne particulate emissions are potentially greatest for the following operations (not necessarily in the order shown):

- Steelmaking (especially when oxygen is used for refining)
- Sintering (especially for modern fluxed sinters)
- Transfer, crushing, screening, and blending of raw materials
- Casting and handling of hot metal from the blast furnace
- Scarfing and grinding of semifinished steel.

Most steelmakers have made at least some progress toward control of fumes and dusts from the above sources, but in each plant there are special difficulties to be overcome. Although the technology for capture of dust by baghouses, scrubbers, or electrostatic precipitators may be well-developed, economic and technical problems may arise where the emission occurs over large areas (as in stocking, storage, and reclaiming operations) or from numerous individual sites (as in sinter processing or coke handling). Many stocking/reclaiming systems require several dumps from overhead clamshell buckets as the ore or coal moves into or out of stock. These are difficult to shroud over an area of several acres.

Of the unwanted gaseous emissions from steel plants, two must be assigned high priority because they release sulfurous gases to the atmosphere. Two steelworks substances, the coke-oven gas and the blast-furnace slag, collect and carry about 75 percent of all sulfur that enters the plant. If the gas is used as a fuel, the hydrogen sulfide in it oxidizes and is exhausted as sulfur dioxide. When the slag is disposed of, it may give off a fraction of its hydrogen sulfide upon weathering, whenever it is wetted by rain or plant water. Economically practical controls for these gaseous emissions are not yet available.

Lower priorities are assigned to control of the emissions from conveyance of raw materials (mostly by rubber belt), from blow-off at stockpiles, from steelworking operations such as rolling, and from the multitudinous dips, baths, and sprays used in steel finishing. Where blow-off from stored solids has intruded into the community, it has usually been controlled by wetting the materials. Dust collectors are sometimes used on high-speed rolling mills, as much for shop cleanliness as for control of air-pollution. The finishing processes are generally amenable to some form of hooding as appropriate to control emissions.

In this steelmaking study, lowest priority is assigned to emissions from the blast-furnace process gases and from powerhouse operations. Because the economic incentive to clean blast-furnace gas for use as an in-plant fuel is strong, it is normally cleaned to 0.01 grain (particulates) per cubic foot, or better. Blast-furnace gas contains little or no sulfur; thus its use for firing stoves or for steam-raising creates no air-pollution problems. Where powerhouses are partly fired with tar or fossil fuels, the emissions are properly classed with those of the power industry. Most steelmakers would be able to convert boilers to use only blast-furnace gas and natural gas, if this became necessary.

Problems

Air-pollution control technology embraces the activities of prevention, containment, and collection of airborne emissions, and these activities may be considered together or separately as the occasion requires. Containment and collection obligate steelmakers to arrange for re-use or disposal of the materials collected.

In the case of coking, the big problem is containment of smoke so that it may be collected or destroyed. A conventional coke-oven battery may have a mile or more of seals associated with its end doors; the operations of charging and pushing require containment of emissions from 400 to 500 additional locations per battery of 100 ovens. Although the ducts and hoods applied to this task might be made movable, the overall problem is such that one control authority has proposed that entire batteries might be "encapsulated" within some kind of building. If this were done, very careful engineering of building ventilation and exhaust systems would be required to assure that overheated, toxic, and/or explosive atmospheres did not form within. Many students of the coke-oven problem feel that a wholly new approach to the coking of coal is preferable, but nothing practical has yet been developed. Steelmakers are concerned that present steps to install shrouds and hoods on conventional coke ovens may prove to be both inadequate and very expensive.

For particulates arising from ironmaking and steelmaking operations, the main problems are those related to containment and disposal, because collection devices are reasonably efficient. An exception occurs in the case of fluxed sinter, where the substances are abrasive toward fabric filters, corrosive toward wet scrubbers, and bipolar (attracted to both wires and plates) in electrostatic precipitators. The cost of providing hoods, ducts, and fans to carry metallurgical fume into collection systems is very high, and technical problems arise in fitting and maintaining hoods near hot operations. Although blast-furnace and sinter-plant dusts may be recycled directly into the sintering operation (coke fines are also usable), the iron oxide fumes from electric-arc steelmaking may require careful burial if there is no adjacent sintering operation. Similarly, certain fumes collected from steelmaking with partly galvanized scrap must be buried because the zinc ferrites they contain are harmful to blast-furnace refractories if recycled in the sinter. The containment of elusive kish particles during casting and handling of blast-furnace iron is a knotty problem because the required drafts tend to cool the molten iron too much.

Although the desulfurization of coke-oven gas may be accomplished by use of soda solutions in closed-cycle equipment, present apparatus does not do a very thorough job. It appears that the cost of cleaning this gas to anticipated standards may far exceed the value of the gas as a fuel. It is not possible to avoid the problem by deciding to flare or vent the gas, because the sulfur compounds would still be released into the atmosphere. As in the case of coking generally, a wholly new approach may be needed. Even if the coal-sulfur could be entirely retained in the coke, almost all of it would be carried into the blast-furnace slag. Slag fumes are another complex problem: the chemical mechanisms which cause slag to emit some of its sulfur are complex and imperfectly understood.

Opportunities

Research and engineering activities conducted by steel companies to solve steelworks emission problems sometimes appear to be directed toward the meeting of public standards which are in turn based upon incomplete understanding of the control task. Investigations appear to have proceeded to the point where there appears to be general recognition that "metallurgical fume" has characteristics different from "smoke" from some other types of processes. This leads to a general conclusion that there might be good reason for applying different standards of measurement or control to "metallurgical fume" than to other types of "smoke". However, what this difference reasonably should be or could be remains undefined. Indeed, even definition of what constitutes "metallurgical fume" is hampered by the sparcity and lack of dependability of published and available data on the amounts, compositions, size consist, and other characteristics of emissions from steelworks processes. Because a large steelworks can hardly be ignored by an air-quality organization, there has been a tendency to apply to steelworks' emissions some measurements (such as opacity and process weight) adapted from information obtained in studies of other industries, and quite possibly not ideal for control of steelworks' emissions. Steelmakers dislike this situation, and quite clearly they should have the opportunity to improve future air-quality standards by determining and disseminating more information pertaining to the actual characteristics of their emissions.

Metallurgical coke made in present-style ovens is not absolutely necessary for the reduction of iron ore (but conventional ironmakers are doubtful about some of the alternatives that have been suggested). By-products from coke ovens no longer have the value that they once did. Present designs of coke ovens seem to lend themselves more to expedients than to true control of emissions. There seems to be a substantial opportunity awaiting the development of an entirely fresh approach to the whole problem of providing dense, stable carbon fuel for the blast furnace. The dearth of good ideas in this problem area would indicate an opportunity for creative engineering of alternate ways to stabilize coal carbon. Note that the blast furnace is an effective desulfurizing reactor. There is no inherent reason why the coaly aromatic compounds (now removed from coal in coking) could not someday be charged (in stabilized form) into the blast furnace and utilized directly. Nonrecovery ovens have been proposed as one way of doing this.

Emission-control costs for particulates are raised by the costs of providing draft from dozens of different fans, and also by the costs of collecting emissions adjacent to many sources. There is opportunity to lower these costs and improve effectiveness in some cases by manifolding both the drafts and their emissions into larger collectors and bigger, more efficient fans of the type used in turbocompressors.* The exhaust might be usable as prewarmed combustion air for stove burners and powerhouse boilers, or as feed air to the blast-furnace turbocompressors. If turbine "superfans" were used, sensitive monitoring of the dust-collection devices would be needed to guarantee against admission of dusty air into the turbines.

The simplest dust-collection devices, plenums and cyclones, have fallen into disuse because they are not efficient enough. There seems to be an opportunity to redesign and improve these types of collectors, if only to reduce the load on more sophisticated equipment.

The above short list of potential opportunities contains no inexpensive or short-term projects, because most opportunities in that category were followed up long ago by steelmakers and equipment suppliers.

---

*Emission-control standards based on process weight per stack tend to raise legal blocks to manifolding.

BLANK PAGE

SECTION V

SPECIFIC COST/EFFECTIVENESS INVESTIGATIONS

Section 305 of the Air Quality Act of 1967 instructs the Department of Health, Education, and Welfare to prepare "...a comprehensive study of the economic impact of air quality standards on the Nation's industries, ... including an analysis of... the cost of controlling emissions to attain such standards of air quality as may be established..." The law also requires annual re-evaluation of these studies and estimates. The economic research activities within the present Battelle project have been an early step in compliance with this part of the law. Specifically, Battelle's task in Phase I has been to develop and pretest methods to be used in the comprehensive study, and to obtain preliminary estimates of control cost by application of the methods.

Before the detail and results of this Phase I cost study are presented in numerical form, the progress of the study will be described in narrative for the orientation of the reader, and the elements of the study method will be discussed.

At the outset of the investigation, the plan was for project teams from Battelle and from the Swindell-Dressler Company to collect a large mass of information relating to both technical and cost aspects of air-pollution control in the steel industry. Sources of this information were to include the published literature, the files of both investigating organizations, and data to be obtained from steel companies, manufacturers of emission-control equipment, governmental bodies, and any other appropriate places.

To facilitate communication with the steel industry, NAPCA appointed an Industry Liaison Committee of 11 men, each representing a major steel company. Early in the project, a meeting was held with this Committee to explain the objectives of the work and to solicit cooperation by the steel industry. During the course of the project, two interim reports (issued by Battelle and Swindell-Dressler to NAPCA) were distributed to each member of the Committee and were discussed at two joint meetings of the Committee with NAPCA representatives and members of the project team. Drafts of the final technical and economic reports were also distributed to members of the Committee and discussed in a fourth meeting.

Although the Industry Liaison Committee was advisory, the interest of its members and the importance of the companies represented affected the data-gathering effort. Field visits and other contacts between the project team and steelmakers were mostly to plants represented on the Liaison Committee and were at times and places arranged by Committee members.

After the first few months of the study, it became apparent that extensive cost information in complete and usable form was not available either from the literature or from contact with the steel companies.* Information for these cost studies must be complete with respect to (1) general description of the nature of the specific steelmaking process, including approximate throughput in tons or other units per unit of time; (2) general description of the air-pollution control system, including flow ratings as appropriate; (3) capital cost, together with the year of installation; (4) operating

---

* The remainder of this discussion is concerned solely with the cost-versus-effectiveness part of the study. Technical studies are covered in a complementary report.

cost; and (5) effectiveness of the system, for example in terms of weight of particulate matter per unit of exhaust from the control apparatus. Although much information bearing on these aspects was collected from the literature and from cooperating steel companies, in only 16 cases was the cost information regarding a single process segment complete enough to permit direct analysis and interpretation of the cost of that installation.

The original intention had been to collect sufficient inputs of cost information to permit direct statistical analysis and the development of specific cost models that could be used to predict costs for other situations. The sparsity of complete data from the expected sources required a modification of procedure. After it became apparent that data would not be available in sufficient quantity to serve directly as a base for preparation of cost models, the Swindell-Dressler staff undertook to develop a body of cost estimates using a number of sources. The estimates covered capital and operating costs for air-pollution control equipment. They were developed by applying the techniques of engineering-project estimation to the available data for a number of steelworks process segments. Because of the impossibility of allowing for all eventualities that might affect costs in specific situations, the Swindell-Dressler estimates were prepared for typical situations and for installations of new process facilities (except in the case of open-hearth steelmaking). Because most emission-control equipment is engineered to clean effluent to about 0.05 grain of particulates per standard cubic foot, the estimates were based on this reference point. Swindell-Dressler also developed both theoretical and practical estimates of the changes in cost that might be expected if other levels of effectiveness of control were applied.

The results of the Swindell-Dressler studies and estimates are presented in Appendix C.

The Swindell-Dressler estimates were then subjected by Battelle to an analysis that led to the development of several primary cost models for each process segment for which Swindell-Dressler had prepared cost estimates. Each such model is a mathematical expression that can be solved for the annual cost of controlling emissions from a particular steelworks process segment. To use the primary model for a situation where cost is to be estimated, two parameters are needed: (1) annual tonnage throughput for the process segment (or holding capacity for batch processes) and (2) effectiveness of the control equipment expressed as level of emissions or other quantifying criteria. If these two parameters can be stated, then to the degree that the model is correct, solution of the mathematical expression yields an estimated value for the annual cost of the control applied or to be applied. Annual cost calculated in this manner from the model combines (1) fixed charges, the annualized portion of capital and capital-related cost,* and (2) annual operating costs.

With completion of the modeling of the Swindell-Dressler estimates, the study entered a pretesting phase in which the object was to compare costs as reported by steel companies for actual installations with calculated cost estimates derived by applying the model to the throughput and effectiveness data for the installations. The concept was that to the extent that reported costs agreed with costs calculated from a model, the primary model derived from Swindell-Dressler's estimates could be demonstrated to have reasonable validity for use in predicting costs in other situations.

---

*Taken at 20 percent of 1968-based capital costs.

Battelle encountered two important problems in this type of pretesting and prediction. First, although the models were based on a large background of what is thought to be valid and reliable engineering and cost information, they were developed for typical stylized systems that almost certainly would differ in design and environment from any particular and specific steelworks case. Second, although cost and effectiveness data may be reported as they apply to a specific set of conditions, experience during this study has shown that there are several reasons why such reported figures may deviate substantially from "typical". Experience has also shown that such deviations usually are not identified when the data are submitted. Because of the interaction of these two types of problems, it is reasonable to expect that when any one specific installation is considered, the annual cost computed by use of the primary model might differ substantially from the reported cost. However, if the model is reasonably correct for the typical situation used in deriving it, then testing of the model against a large number of accurate reported cost values should show reasonably good statistical agreement.

METHODOLOGY

The following elements of method were applied to the cost/effectiveness studies of Phase I:

(1) Swindell-Dressler prepared engineering estimates of costs for air-pollution control.

(2) The form of a representative model was defined in mathematical terms, and a version of this model was applied to the Swindell-Dressler estimates.

(3) Data were gathered from several sources for use in pretesting.

(4) The findings from modeling and pretesting were interpreted.

This part of Section V describes the procedures and results obtained as experienced for specific inquiry into 15 selected steel-industry process segments. Section VI suggests recommended future procedures and methods as determined from the experiences of Phase I.

Engineering Estimates

The final report of Swindell-Dressler Company (Appendix C) is a basic reference for the modeling and pretesting studies of Phase I. It contains engineering estimates of capital and operating costs for several types of air-pollution controls as applied to a number of steelworks processes. It also contains information about the factors that may cause actual control costs to vary from case to case, especially in the event of allowable emissions higher or lower than 0.05 grain per cubic foot.

The Swindell-Dressler estimates are representative of the type that might be prepared by NAPCA or contractors wherever control-cost data are required but are not available from industry sources. Note, however, that Swindell-Dressler was unable to prepare similarly accurate estimates of control cost for situations where control technology has not been worked out, e.g., for the charging of coke ovens. It is also to be noted that the estimating procedure, which is based on experience, does not necessarily extrapolate well to situations where experience is meager. (For example, the Swindell-Dressler engineers express concern about the accuracy of estimating costs for the unusual application of fabric filters to open-hearth furnaces.) Caution should be exercised in preparing and using estimates in situations where there is meager experience and where twofold to threefold errors may occur.

The Swindell-Dressler estimates produced for the Phase I studies are a useful body of information for the following three purposes:

(1) They describe the probable costs of controlling certain forms of steelworks air pollution, for the typical case

(2) They permit the calculation of primary mathematical models which summarize control costs as a function of process throughput and effectiveness, and which facilitate interpolations

(3) They can be compared, directly or in modeled form, with costs reported for actual situations, as a pretest of the estimating and modeling procedures.

The degree of agreement between the modeling forms and expressions and the estimates prepared by Swindell-Dressler helps to evaluate the modeling method as applied to highly coherent, orderly sets of data. The degree of agreement found between the Swindell-Dressler estimates (or models made from them, if the models are accurate) and the costs reported by the steel industry help to determine generally the usefulness of engineering estimates as data supplements. But these pretests do not determine the applicability of the modeling methods to analysis and characterization (and eventually projection) of steel industry data as such. Applicability could be determined accurately only by statistical assessment with real cases.

Definition of the Form of the Model

Battelle proposed in November, 1968, that a simple equation of the general form

$$\text{Cost} = (A^z) \times (B^y) \times (C^x) \ . \ . \ . \times (N^m)$$

could be used to correlate and evaluate economic cost-effectiveness data pertaining to either (1) capital costs or (2) annualized capital costs combined with operating costs, for air-pollution controls. A specific adaptation of the general equation was made for primary application and pretesting of the idea in Phase I. The adaptation proposed that annual overall cost (operating costs plus fixed charges of 20 percent of 1968 capital costs) may be described by

$$\text{Cost} = A^1 \times (\text{Throughput})^b \times (\text{Effectiveness})^g$$

where cost (C) is expressed in dollars per year, A is the "standard" overall cost per year at reference throughput and effectiveness, throughput (T) is expressed in millions of tons per year with a reference point of 1 million tons, and effectiveness (E) is expressed in arbitrarily chosen units, with a reference point of E=1 corresponding to the national or regional norms for air-pollution control. According to these definitions, the trivial exponent (1) on term A may be dropped to give the short algebraic form:

$$C = A \times T^b \times E^g \quad .$$

For a specific process segment operated at a throughput of 1 million tons per year at normal or reference control effectiveness, C=A irrespective of the numerical values of the exponents b and g. These exponents describe the sensitivity of cost to variations from reference throughput and reference effectiveness. This is an abbreviated or minimum version of the model, adjusted to the specific purpose of modeling Swindell-Dressler's estimates. The proposed general model is not limited to only throughput and effectiveness factors, and it is expected that additional factors would be required for accurate modeling of industrial data. For example, higher control costs are expected for sintering plants operated at high basicity ratio, and an additional factor and sensitivity exponent would be required to express this effect. The criterion for adding factors to the model is that they must take the value 1.0 under some arbitrary reference condition. The use of extra factors is justified wherever they can improve the fit of the equation to the data.

The suggested primary modeling expression depends for its usefulness upon a selective and judicious definition of E, the effectiveness coefficient, for each process segment studied.* Where emissions are in the form of particulates suspended in air or other gases, and where measurements are feasible, E may be objectively defined in terms of the dust loading in the outlet gases emanating from the control device. For example, many gas-cleaning systems are built to the specification that the outlet air or gas shall contain less than 0.05 grain of total particulates per standard cubic foot. This amount corresponds roughly to the threshold of dust visibility in many cases, and satisfies some air-quality codes.** Because this specification was used uniformly by Swindell-Dressler, it was found to be convenient to define

$$E = \frac{0.05}{R}$$

where R is the outlet loading of particulate matter in grains per standard cubic foot of gas. This definition is essentially simple. It takes the value

---

*Industry representatives point out that the present definition of E as given here may be unsatisfactory in statistical modeling of industrial data, because the construction or upgrading of industrial air-pollution controls is based on specific performance criteria for specific locations and situations.

**The origin of the 0.05 grain standard is to be found in early work in Allegheny County, Pa., which included studies by United States Steel and Jones & Laughlin Steel on emissions from open-hearth stacks. This work was done prior to use of oxygen in steelmaking. Much metallurgical fume, and especially oxygen-refining fume, is quite visible at a concentration of 0.05 grain per cubic foot, thus the reference point may no longer be satisfactory. California's code is based upon a lower grain loading.

$$E = \frac{.05}{.05} = 1$$

for the standard or reference condition where R = .05 grain per cubic foot outlet loading, and it varies in the appropriate sense, rising as the outlet dust loading decreases, and vice versa. In other kinds of situations, such as for gaseous emissions or in non-ducted systems, E may become more complex or even a matter of judgment.

A typical primary cost model, developed in this study from Swindell-Dressler estimates, takes the form

$$C = \$623,000 \times T^{0.67} \times E^{0.19} \quad .$$

(This particular example is for wet scrubbers applied to control of dust in a sinter plant.) At reference conditions of 1 million tons throughput (as sinter produced) and 0.05 grain of particulates per cubic foot in the scrubber exhausts, T (throughput) and E (effectiveness) both take the value 1.0. Thus C takes the value $623,000 per year (which equals A) for the total or overall cost, which is operating cost plus the annualized portion of capital cost.

For any other condition of tonnage and effectiveness, appropriate values of T and E must be inserted into the model expression and raised to the powers shown. For example, if the rate of sinter production is 2 million tons per year, then T becomes 2, and if the desired effectiveness is 0.03 grain per cubic foot of effluent, E becomes $\frac{.05}{.03} = 1.67$.

The exponent 0.67 applied to the new value of T indicates that the cost, C, will increase by about 59 percent when the throuput of sinter is doubled, and the exponent 0.19 applied to the new value of E will increase the cost by an additional 10 percent. The new overall cost is obtained by the expression

$$C = \$623,000 \times 2^{0.67} \times 1.67^{0.29} = \$623,000 \times 1.59 \times 1.10 = \$1,090,000 \quad ,$$

which combines the effects of changes in throughput and effectiveness.

The application of the general model to NAPCA's task of analyzing costs for air-pollution control at various levels of effectiveness is best made through statistical analysis of large amounts of industrial information. For example, data on the control costs, throughputs, and attained effectiveness of controls in 30 sinter plants might be reduced by regression analysis to derive best-fit values for A, b, g, and exponents for other factors as may be required. The resulting model would then be used to project costs for control of sinter plants on a regional or national basis. Directory information would give (or permit estimation of) throughputs for each plant, and the values of E would be assigned by NAPCA. The overall regional or national cost would be the sum of individual plant costs as projected by the model. To assess costs for the whole steel industry, a separate model could be prepared for each process segment contributing to pollution-control costs.[*]

---

[*] In the example of the Swindell-Dressler estimates, separate models were prepared for each type of control system too. This would not be necessary in the analysis of industrial data because it could be assumed that the least costly system for a given level of control would be installed in each case.

Two defects appear in this ideal approach. The first is that some steelworks emissions are uncontrolled or poorly controlled, and for these processes no amount of industry assistance can produce data for analysis to form models.* Also, the gaps in the steel industry's internal information systems may limit the number of inputs available for even the best-controlled process segments. In light of these situations, the best route to analysis, although a limited one in terms of accuracy, may be to supplement or synthesize data by careful study and engineering estimation procedures. In some instances, however, these procedures can yield only order-of-magnitude estimates. Section VI develops the possible methodologies in greater detail.

The mathematics of the proposed primary cost model are simple, and a discussion of this topic aids in appreciation of the model's validity for this study. Consider three-dimensional space, with three axes of this space intersecting at right angles. This is so-called Cartesian space, which also corresponds to the real world. Name the axes C, T, and E, such that various distances along each axis correspond to various values of cost, throughput, and effectiveness from the primary model expression. Figure V-1 illustrates the axes as intersecting heavy lines.

If either T (throughput) or E (effectiveness) is zero, C (cost) must be zero, because no control cost should be incurred if no control is achieved or if the process is inoperative. Thus the value of C, which is the height of points above the basal plane T-E, must be zero along the T and E axes. For nonzero (and implicitly positive) values of T and E, C has some positive value represented by a height above the T-E plane. The following facts are known about values for C:

(1) At the location where both T and E equal 1, the value of C is A; A is the height above the plane

(2) For any constant value of E, increases in T produce increases in C

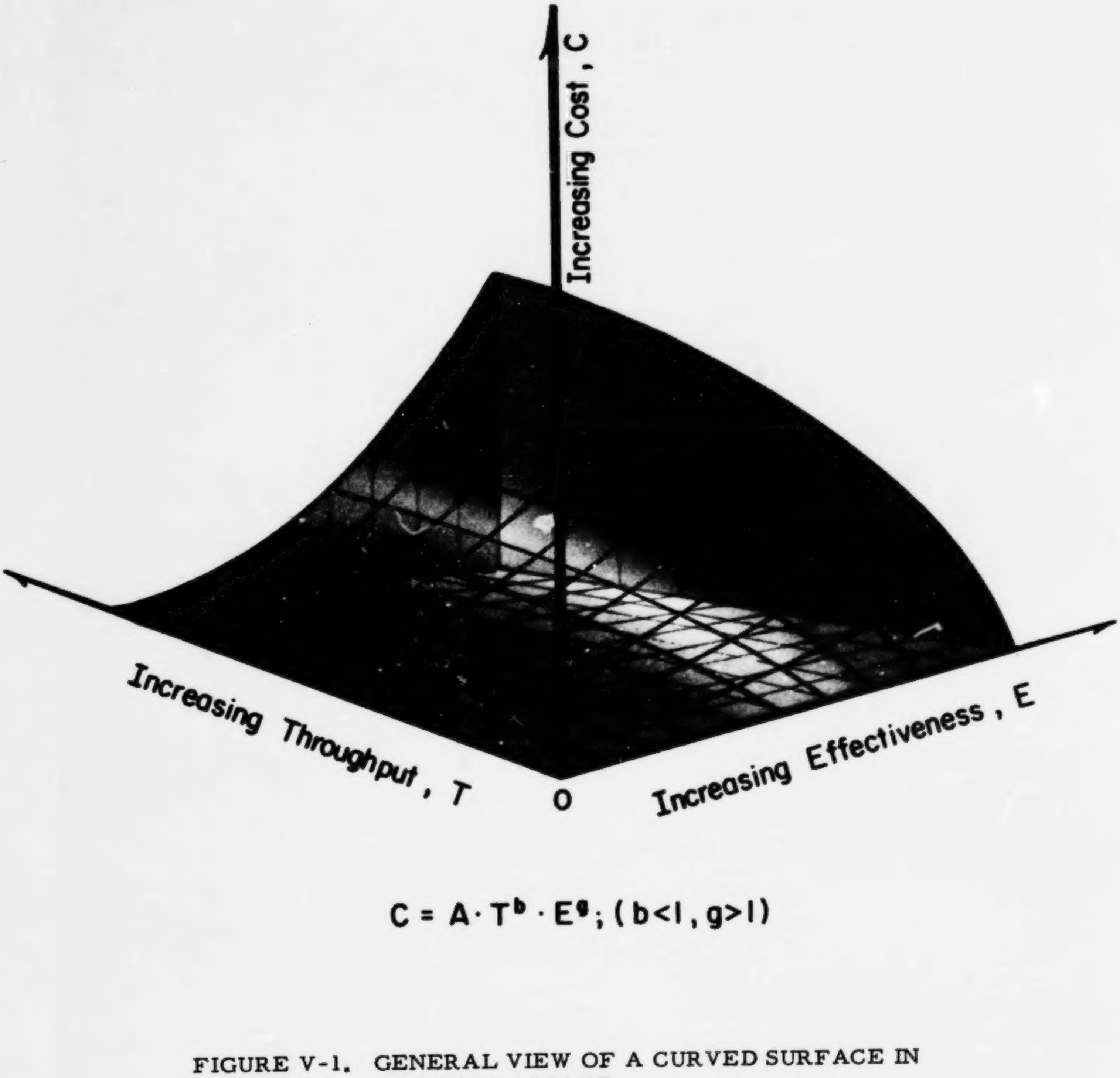
(3) For any constant value of T, increases in E produce increases in C.

Logically, then, the C-values form a surface that trends upward as the values of T and E increase. The rate and curvature uptrend depend on the exponents b and g. In Figure V-1, the surface has been depicted to show how two different curved tendencies (one concave, one convex) can combine to form the surface of C-values.

The application of the primary model may be made entirely with conventional "canned" computer programs requiring no detailed appreciation of the mathematics involved. The point of reviewing the mathematics is that it may be seen that the equation proposed describes a general surface that may be curved or moved by adjusting the values of b, g, and A. This surface has the property that it is monotonic, i.e., always upward-trending as either T or E increases. Finally, it may be complexly curved as shown in the figure. Clearly, this kind of model surface may be fitted to the real world of air-pollution control costs as well as any other. Battelle proposes that this is the simplest surface having the required properties.

---

*Emissions in the uncontrolled category include a number of less-significant contributors to the overall problem.


Increasing Cost , C
Increasing Throughput , T
0
Increasing Effectiveness , E

$$C = A \cdot T^b \cdot E^g; \ (b<1, \ g>1)$$

FIGURE V-1. GENERAL VIEW OF A CURVED SURFACE IN CARTESIAN SPACE

Data Gathering

Two different approaches to the gathering of cost data from steel companies were tried by Battelle. The first took the form of direct all-day interviews conducted between September, 1968, and February, 1969. Twelve steel companies were visited; ten of these were represented on the Liaison Committee. These visits were intended to be comprehensive in two senses – they were to cover all process segments in each plant, and they were to obtain all relevant technical and economic data.

For purposes of the study of cost versus effectiveness for air-pollution controls, the all-day visits were not particularly productive. Three kinds of data "blocks" were encountered:

(1) Technological blocks were encountered wherever air-pollution problems have not been solved in practical ways. (A large number of steelworks emissions fall into this category.)

(2) Information blocks appeared in the case of newly-installed control equipment having no cost history, and also where plant accounting systems were not amenable to read-out or analysis of operating costs for air-pollution controls.

(3) Policy blocks were encountered in varying degrees from company to company. (Many steel companies characteristically do not reveal data descriptive of capacities, rates of operation, or costs. The restrictive policies are of long standing, and apply especially to inquiries regarding costs.)

Most larger steel companies do exchange current technical and operating statistics (excluding costs) on an intramural basis through the American Iron and Steel Institute, but the usual public release of this information is in the form of industry totals and averages published from time to time by the AISI. In April, 1969, the Board of Directors of AISI approved Battelle's use of certain quarterly reports for the last two quarters of 1968. The approval was granted as a one-time, nonrecurring use for the purpose of these studies, and certain confidentiality precautions would be observed. Battelle was unable to make use of the AISI quarterly operating reports in this present study because access to the reports was granted too late in the contract period.

A second data-gathering approach was made in which both the scope and the depth of inquiry were considerably abbreviated. Nine steel companies, each represented on the Liaison Committee, were invited to prepare summary sheets describing their cost/effectiveness experiences in controlling air-pollutant emissions from 15 selected process segments within their plants. The blank summary sheets are bound into this report as Appendix B. They request the following information:

(I) Identification (company and person responding*)

(II) Type and capacity of the operation for which information is offered (for evaluation of the throughput, T)

(III) Brief non-technical description of air-pollution controls in use

(IV) Estimated capital costs and escalation factors (to determine the capital portion of overall costs)

---

*Identification was included solely to permit the Battelle project staff to call back to resolve questions.

(V) Estimated operating costs (qualified as to credits included and man-hours applied)

(VI) Estimated overall effectiveness of control (objective or subjective estimates according to measurability).

The selection of 15 specific process segments for inquiry in the second approach was based on several criteria, including severity of the problems, representation of a number of process types, and focus upon those situations for which the steel industry should have the best information. A worksheet decision matrix showing this selection was bound into the Second Interim Report dated January 31, 1969, and the list of process segments with selections marked for emphasis is given in Table V-1.

The second (summary sheet) approach to information-gathering did not overcome the technological blocks. Battelle's willingness to accept estimates and subjective judgments may have cleared away some informational blocks, but the summary sheets added only a little to the information already obtained by interviewing. Some companies indicated that the summary-sheet approach might have been more acceptable if the sheets were submitted to and processed by AISI or by the Industry Liaison Committee. These trusteeship possibilities were not explored because time in Phase I was too short, but they do offer potential for future use.

The use of summary sheets was adjudged to be a good information-gathering technique because:

(1) They constitute a specific inquiry, with uniform definitions and with certainty that the same information is asked of every source

(2) They are convenient for the steel companies to handle because they minimize the physical work of preparation and because they may be mailed to other locations if the information sought is decentralized in the company or in a given plant

(3) They are amenable to trusteeship processing if necessary.

A mass-mailing approach to information-seeking is inappropriate. The proper use of the summary sheets is as a format for steel-company responses after personal contact has been made. In future inquiries, the summary sheets could be left at the end of the interview for later preparation and return.

Modeling, Pretesting, and Interpretation

The combined efforts yielded usable information pertinent to eight of the process segments selected for intensive study. Of these, four had been studied extensively by Swindell-Dressler. In all, 17 mathematical models were derived by analysis of the Swindell-Dressler estimates. The specific steps taken were as follows:

(1) The Swindell-Dressler estimates (prepared for a reference outlet grain loading (R) of 0.05 grain) were expanded to reflect two additional levels of effectiveness. Costs were altered according to factors derived by

TABLE V-1. AIR-POLLUTION CONTROL PROBLEMS CONSIDERED IN PHASE I STUDIES

Coking Operations	
Coal receiving and storage	(unloading, stocking, and reclaiming)
Coal handling	(blending and pulverization)
● Coke-oven charging	
● Coke-oven seals	(end-door seals in particular)
● Coke-oven pushing	
● Coke quenching	
Coke handling	(wharfing, transfer, breaking, screening)
● By-products recovery	(particularly vents and drains)
● Coke-oven gas systems	(specifically desulfurization of the gas)
Ironmaking Operations	
Ore and flux receiving and storage	(unloading, stocking, and reclaiming)
● Ore and flux handling	(transfer, comminution, sizing)
● Sintering	
● Pelletizing	(as practiced at mining sites)
● Blast-furnace charging	(stockhouse, skip, and bell operations)
Blast-furnace smelting	(wind and top-gas systems)
Casting and flushing	
Pigging (of iron)	
● Slag disposal	(either by granulation or by dumping)
Power Generation	
Fluid-fuel boilers	
Solid-fuel boilers	
Steelmaking	
Scrap handling	(unloading, cutting-up, baling, and charging)
Flux handling	(unloading, storage, reclaiming, and charging)
Hot-metal handling	
● Steelmaking	(melting, refining, and tapping – all methods)
● Steel teeming	(ingot practice or continuous casting)
Steelworking	
Soaking, reheating, etc.	(includes annealing and heat treatment)
Primary breakdown	
● Conditioning of slabs	(scarfing and grinding)
● Hot rolling/forging	(includes all hot-forming operations)
Acid pickling	
Cold rolling/forging	
Finishing Operations	
Cleaning and degreasing	(solvent or detergent bath and spray steps)
Hot-dip coating	(hot galvanizing, tinning, terneing)
Painting	
Cold-dip coating	(conversion coating, oiling, etc.)
Electrocoating	
General	
Plant waste incineration	(burning of garbage, tar, etc.)

● Denotes problems receiving specific economic emphasis.

Swindell-Dressler from theoretical studies and other sources (also presented in full in Appendix C). Where effectiveness-scaling factors were not available, they were estimated by Battelle.

As an example, Swindell-Dressler reported an overall operating cost of $277,000 for an electrostatic precipitator applied to an electric-arc furnace of 150-ton nominal capacity. Swindell-Dressler also reported a variation of 10 percent in operating cost for electrostatic precipitators applied to arc furnaces in cases where the outlet grain loading varied to 0.02 grain (costs up 10 percent) or 0.125 grain (costs down 10 percent) per standard cubic foot. The following scalings resulted:

R, grains per cubic foot	E = .05/R	Cost Estimated
0.05	1	$277,000 (base)
0.02	2.5	$277,000 x 1.1 = $305,000
0.125	0.4	$277,000/1.1 = $251,000

In the case of electric-arc furnaces equipped with other kinds of gas-cleaning equipment, Swindell-Dressler did not report effectiveness-scaling factors. Working from other Swindell-Dressler estimates for venturi scrubbers, and from commentary on the variance for baghouses, Battelle estimated a factor of plus and minus 15 percent for scrubbers and plus and minus 10 percent for baghouses.

(2) The Swindell-Dressler estimates were also scaled to obtain values for the throughput, T. In the case of sintering, the calculation was based on a 330-day operating year. In the case of pelletizing, 8000 operating hours per year was used. For the three steelmaking processes, scaling was based on an 8000-hour year with tap-to-tap times of 2.5 hours for the arc furnace, 1 hour for the basic oxygen furnace, and 8 hours for the open hearth.

(3) Finally, the Swindell-Dressler data were scaled according to factors (given in the text of Appendix C) to represent steelmaking shops as follows:

   (a) An electric-arc-furnace shop with two furnaces operating simultaneously and ducted to a single collector

   (b) A basic-oxygen furnace shop with alternate use of one of two furnaces ducted into a single collector

   (c) An open-hearth-furnace shop with six furnaces, each having its own dust-collection system.

(4) The data resulting from these scaling operations (data are given in full in the next part of Section V) were analyzed by multiple linear regression against the linearized form of the primary modeling equation:

$$\log (C) = \log (A) + b \times \log (T) + g \times \log (E) \quad .$$

The regression analyses yielded specific models, including values for A, b, and g in each case. The closeness of fit was also reported as a part of the regression statistics. Where it appeared that data for different apparatus applied to the same process segment might agree well, combined regressions were performed. This technique, where successful, lessens the number of individual models required.

The purpose of modeling, aside from characterization of Swindell-Dressler's estimates of control costs in a form easily interpolated, was to determine how well the modeling expression could represent the values and variances estimated by Swindell-Dressler and by Battelle.

Pretesting followed. The purpose of pretesting was to determine how well the Swindell-Dressler data, as represented by the models, agreed with cost-effectiveness information obtained from steel companies. This form of pretesting did not ascertain how well the primary model might fit reported data from the steel companies. A minimum of ten, perhaps more, inputs would normally be required to generate a model of any one process segment using steel-company data only. The steps of pretesting were as follows:

(1) The data reported by steel companies were scaled to obtain values of C, T, and E on a basis comparable with the scaling used for the Swindell-Dressler data. E values were computed according to the definition E = .05/R, where R is grains of particulates per cubic foot of effluent gases. T values were scaled from reported capacities by applying the same tap-to-tap times (for batch steelmaking processes) as had been used to scale the Swindell-Dressler figures.

(2) The coefficients and exponents (A, b, and g) obtained in the modeling of the Swindell-Dressler estimates were applied to the throughput and effectiveness values for each of the pretest cases reported by industry, and estimated overall operating costs were computed. These computed costs were then compared to costs derived by adding reported operating costs to reported capital costs (annualized at 20 percent per annum) as given by the industry sources. The discrepancy of comparison was calculated in each case by the following formula:

$$\text{Discrepancy} = \frac{(\text{Cost Reported}) - (\text{Cost Estimated From Model})}{.01 \times (\text{Cost Reported})} .$$

(Units of discrepancy were percent of reported cost.)

The specific results of all modeling and pretesting operations are presented in the next (and concluding) portion of Section V. Battelle has not yet analyzed sufficient data for any of the sources of steelworks air pollution. It would be premature to apply the results of modeling the Swindell-Dressler data or any other results from Phase I to direct characterization of regional or national control costs. From 10 to perhaps 30 reliable inputs of data representing actual installations would be required to establish a single model with reliability suited to the purpose of projection.

RESULTS AND ANALYSIS

This part of Section V presents the specific results obtained from the application of the proposed methodology to 15 steelworks process segments where air-pollution controls are needed. The selection of these segments was illustrated in Table V-1. The data from the Swindell-Dressler estimates were extensively scaled, as has been described, and the data from actual installations in steel plants were also scaled in the case of batch processes such as steelmaking. Data submitted by steelmakers were not identified as to source, and information offered in incomplete form (generally lacking some costs) were not used at all. A shortage of industry data in some instances limited the amount of pretesting that could be accomplished. Seven of the 15 topics were not represented by industry cost data.

The following discussions and tables are arranged topic by topic. They present all of the results of economic modeling and pretesting from Phase I.

Coke-Oven Charging

Swindell-Dressler sought to prepare estimates for air-pollution controls applied to coke-oven charging, but was unable to do so for lack of cases to study. There are a few partially successful control systems in Canada and Europe, but most are not very effective, and few or no cost or effectiveness data have been released. Similarly, steel-industry sources in the United States responded that no true controls exist for air pollution from this process segment.

Coke-Oven End-Door Seals

Sources within the steel industry reported the existence of maintenance programs for coke-oven door seals. There may be a mile or more of such seals on a battery of 100 coke ovens. Two specific reported figures were as follows:

Annual Cost	Coke Production	Reported Effectiveness
$243,700	1.4 million tons	"Best available technology yields inadequate control"
$68,700	0.84 million tons	"Meets public standards fully"

The above costs work out to 17.4 cents per ton of coke in the first case, and 8.2 cents per ton in the second case. The degree to which these reports were not coherent with one another illustrates the problem of collecting data. Although most companies have seal-maintenance programs, the results are quite variable. Additional inputs to this study were blocked for lack of information.

Coke-Oven Pushing

Swindell-Dressler could not locate, nor did industry sources provide, cost-effectiveness information on the subject of pushing of coke. Two industry sources stated that their efforts center on coking the coal thoroughly and evenly so that no uncoked coal (the principal source of smoke) is pushed. The ability of a plant to do this depends upon factors such as the required operating rate, the regularity of demand for coke, the rank and quality of coals used, and the age, condition, and design of the ovens. Quantitative economic study of cost versus effectiveness was blocked by technological deficiencies. There are apparently no specific controls applied in the United States.

Quenching of Coke

One source in the steel industry reported information on the use of louvered baffles within the quenching towers in one plant. The baffles mechanically restrain the coke particles driven upward by thermal draft during quenching. Costs at the cited plant (with capital costs annualized at 20 percent) amount to $12,600 annually. Operating costs were reported to involve only minor maintenance. The plant produces 1.4 million tons of coke per year; thus, costs are about 1 cent per ton of coke. There are other plants with similar installations, but further study was blocked by lack of information on the part of the steel companies; most installations of quench-tower baffles are quite recent.

By-Product Processing

Steel-industry sources furnished information about two installations covering different sectors of the by-product plant. One such installation (which ignites and flares surplus coke-oven gas) costs about 39 cents per ton of coke to own and operate. A different installation (for which no costs were reported) collects, scrubs, and burns fumes from the processing of tar. Neither installation is a comprehensive control. Quantitative study of this topic was blocked primarily because overall control of by-products fumes is not yet practiced.

Coke-Oven Gas Systems

There is some equipment installed in this country for the purpose of desulfurizing coke-oven gas, but some of it is idle.* Industry sources gave costs for two installations (both old) which annualize to $96 and $23, respectively, per million cubic feet of gas desulfurized. The effectiveness of these installations, which are based on two different ways of absorbing hydrogen sulfide in a soda solution, is only about 65 to 70 percent (as removal of inbound hydrogen sulfide). It was concluded that even partial desulfurization carries a cost of from 4 to 18 cents per million Btu in the gas.

The advanced age of the less-expensive installation (dating originally from 1928, with modifications and rebuilds in 1940 and 1948) makes the annualization of its capital costs unreliable. The higher figure (18 cents) is probably more representative, but the fuel value of coke-oven gas is only about 35 cents per million Btu (more or less depending on internal accounting practices). More complete desulfurization could double costs; thus Battelle concluded that the cost of completely desulfurizing coke-oven gas would probably exceed its nominal value as a fuel. Note that the existence of the coking process obligates the steelmaker to burn or dump this gas in one way or another. Further quantitative study of costs was blocked by the sparsity of control systems and by the lack of cost information on hand within the steel companies.

---

*Stream desulfurization of coke-oven gas concentrates but does not alleviate the air-pollution problem unless the sulfur is recovered from the hydrogen sulfide.

Ore and Flux Handling

The literature and the steel companies which were contacted reported no comprehensive controls. One respondent reported the occasional use of fog nozzles to dampen dusty fluxes. Coal is considered to be more of a handling problem than ore or flux because coal particles average smaller and lighter, hence become airborne more readily. Analysis of the economics for control of this process segment was blocked by lack of comprehensive technology and by inadequate cost information on present practices.

Sintering

Swindell-Dressler reported on the estimated cost of controls for both the draft systems and the materials-handling areas of sinter plants. Two levels of throughput (1000 and 6000 tons per day) were considered. These figures were annualized on a 330-day basis to 0.33 and 2.0 million tons per year, respectively. Factors of cost variation with varying control effectiveness were estimated by Swindell-Dressler for electrostatic precipitators, and these same factors were applied by Battelle to the use of wet scrubbers and fabric filters as well.*

The results of modeling and pretesting the Swindell-Dressler estimates for sinter plants are given in Table V-2. Data were furnished by two steel companies for pretesting purposes. One of the reported cases was based on reworking of an old dust-collection system; the other was based on high-efficiency collection in the materials-handling system, but low effectiveness of collection in the draft system.

The models represented the estimated data well, and explained all of the variation in log (C). This "accuracy" was forced because there are only two values of throughput in the Swindell-Dressler data, such that a perfect line may be drawn between them on a plot of C versus T. When the data for wet scrubbers, electrostatics, and fabric filters were combined for analysis, the modeling process represented log C to within 7 percent. This corresponds to an error of up to about 25 percent in annual cost if the combined model were used. Data received from industrial sources were inadequate to test the direct statistical application of the modeling method.

---

*The potential error introduced by this procedure is moderate. If the value of the g exponent is in fact 0.1 or 0.3 instead of the 0.2 derived by assumption, the maximum error (in the range of E studied) is 11 to 15 percent for C.

The estimated standard cost of controls (roughly 40 to 60 cents per ton of sinter) is almost 10 percent of the value of the sinter to ironmakers.

TABLE V-2. DATA, MODELING RESULTS, AND PRETESTS FOR SINTERING PLANTS

Control Used	Cost per Year	Throughput, million tons	Grains Dust at Outlets	Effectiveness Coefficient
	Data: As Expanded With Effectiveness Factors			
Low-energy wet scrubbers	\$ 251,000 = C(a)	0.33 = T	0.125 = R	0.4 = E
	298,000	0.33	0.05	1.0
	353,000	0.33	0.02	2.5
	827,000	2.0	0.125	0.4
	989,000	2.0	0.05	1.0
	1,184,000	2.0	0.02	2.5
Electrostatic precipitators	182,000	0.33	0.125	0.4
	217,000	0.33	0.05	1.0
	259,000	0.33	0.02	2.5
	590,000	2.0	0.125	0.4
	708,000	2.0	0.05	1.0
	851,000	2.0	0.02	2.5
Fabric filters	162,000(a)	0.33	0.125	0.4
	193,000	0.33	0.05	1.0
	231,000	0.33	0.02	2.5
	560,000	2.0	0.125	0.4
	673,000	2.0	0.05	1.0
	810,000	2.0	0.02	2.5

Models Obtained by Regression Analysis of Above Data

For low-energy wet scrubbers: $C = \$623,000 \times T^{.67} \times E^{.19}$

For electrostatic precipitators: $C = \$449,000 \times T^{.66} \times E^{.20}$

For fabric filters: $C = \$417,000 \times T^{.69} \times E^{.20}$

For combined data: $C = \$489,000 \times T^{.67} \times E^{.19}$

Results of Pretesting

Reported Industry Data			Calculated Cost	Percent Discrepancy(b)
Cost	Throughput	Effectiveness		
\$ 347,000(c)	1.053	0.5	\$ 406,000	-17
\$1,494,000	5.2 (3 units)	0.5 approx. (d)	\$1,701,000	-14

(a) Variation of cost with effectiveness was estimated.

(b) Percent discrepancy = $\frac{\text{(Reported cost) - (Calculated cost)}}{.01 \times \text{(Reported cost)}}$ in this and subsequent tables.

(c) Estimated in advance of installation.

(d) Materials handling system effectiveness = 10; windbox system effectiveness = 0.15. (Modeled separately for this pretest.)

Pelletizing

Swindell-Dressler estimated costs for wet-scrubber controls in the materials-handling portion of a 1.5 million ton-per-year pellet plant, and for cyclones on the dryer exhausts in the same plant. Swindell-Dressler also furnished estimates for a cyclone control system in a 60 ton-per-hour plant using a shaft furnace. These latter data were scaled to 0.4 million tons annually on the basis of 8000 operating hours per year. A variation cost with effectiveness amounting to 20 percent for a 2.5-fold change in average outlet particulates loading was estimated by Battelle to facilitate modeling, as presented in Table V-3. This model was also forced; no true fitting was involved. At any rate, the estimated costs did not include dust controls for the loading of boats or trains at the pellet-shipping point, and this may be the most important problem.

Steel companies furnished no information on pelletizing-dust controls.

TABLE V-3. DATA AND MODELING RESULTS FOR PELLETIZING PLANTS

Controls Used	Cost per Year	Throughput, million tons	Grains Dust at Outlets	Effectiveness Coefficient
Data: As Expanded With Effectiveness Factors				
Cyclones and wet scrubber	\$143,700[a]	0.5	0.125	0.4
	172,500	0.5	0.05	1.0
	207,000	0.5	0.02	2.5
Cyclone and wet scrubber	176,000[a]	1.5	0.125	0.4
	211,000	1.5	0.05	1.0
	253,000	1.5	0.02	2.5

Model Obtained by Regression Analysis of Above Data

For combined data: $C = 196,000 \times T^{0.18} \times E^{0.20}$

Results of Pretesting: None - no cost data supplied for actual installations.

---

[a] Variation of cost with effectiveness was estimated.

Blast-Furnace Charging

Systems for the control of dusting in stockhouses and furnace charge hoppers exist, but they differ considerably from place to place. The sources in the steel industry furnished no data on capital or operating costs for this equipment, apparently because costs for these controls are not separable from other charging and stockhouse costs. Most controls are confined to the screening operations and transfer points within the stockhouses.

Ironmaking Slag Disposal

Neither the literature nor the steel companies contacted by Battelle furnished cost information on the prevention or containment of sulfurous fumes during the flushing and disposal of blast-furnace slag. However, this topic is being researched by the American Iron and Steel Institute at present.

Steelmaking

The general subject of air-pollution controls for steelmaking was studied carefully by Swindell-Dressler, and the resulting estimates were the most complete of the entire study. Similarly, steel companies furnished a relatively substantial amount of information. Specific results of modeling and pretesting are presented separately for the different processes.

Electric-Arc Steelmaking

Swindell-Dressler prepared estimates for the costs of controlling emissions in new installations, for three sizes of arc furnaces, and by three different collection methods. Specific estimates of the variability of cost with effectiveness were made for two of the control systems, and Battelle assumed a variability factor for purposes of modeling the third system. Data, modeling results, and pretest information are given in Table V-4. An attempt was made to prepare a combined model for all three types of controls, but the agreement was poor. In scaling both the estimates and the data obtained from steel companies, a tap-to-tap time of 2.5 hours was used.

The cost data obtained from steel companies for use of baghouses to collect arc-furnace fume included three sets of points. This permitted a separate solution to derive parameters A, b, and g of the modeling expression. Although the resulting expression is too narrowly based in data to be dependable for projections, it is interesting to contrast the parameters of the Swindell-Dressler baghouse model with those obtained in the case of the data from steel companies:

Source of Data Modeled	Model Parameters A	b	g
Swindell-Dressler; value for g estimated by Battelle	$285,000	0.66	0.11
Steel companies	$450,000	0.96	1.5

TABLE V-4. DATA, MODELING RESULTS, AND PRETESTS FOR ELECTRIC-ARC FURNACES

Control Used	Cost per Year	Throughput, million tons	Grains Dust at Outlet	Effectiveness Coefficient
	Data: As Expanded			
High-energy wet scrubbers	$149,000 = C(a)	0.16 = T	0.125 = R	0.4 = E
	164,000	0.16	0.05	1.0
	189,000	0.16	0.02	2.5
	429,000	0.96	0.125	0.4
	472,000	0.96	0.05	1.0
	542,000	0.96	0.02	2.5
	614,000	1.6	0.125	0.4
	676,000	1.6	0.05	1.0
	778,000	1.6	0.02	2.5
Electrostatic precipitators	95,000	0.16	0.125	0.4
	105,000	0.16	0.05	1.0
	116,000	0.16	0.02	2.5
	251,000	0.96	0.125	0.4
	277,000	0.96	0.05	1.0
	305,000	0.96	0.02	2.5
	363,000	1.6	0.125	0.4
	400,000	1.6	0.05	1.0
	440,000	1.6	0.02	2.5
Fabric filters	77,000(a)	0.16	0.125	0.4
	86,000	0.16	0.05	1.0
	95,000	0.16	0.02	2.5
	247,000	0.96	0.125	0.4
	274,000	0.96	0.05	1.0
	304,000	0.96	0.02	2.5
	354,000	1.6	0.125	0.4
	393,000	1.6	0.05	1.0
	436,000	1.6	0.02	2.5

Models Obtained by Regression Analysis of Above Data

For high-energy wet scrubbers: $C = \$505,000 \times T^{.61} \times E^{.13}$

For electrostatic precipitators: $C = \$296,000 \times T^{.57} \times E^{.11}$

For fabric filters: $C = \$285,000 \times T^{.66} \times E^{.11}$

Results of Pretesting

Reported Industry Data			Calculated Cost	Percent Discrepancy
Cost	Throughput(b)	Effectiveness		
$691,000	0.64	1	$385,000	+44
65,200	0.134	1	75,600	-16
705,000	1.6	1	492,000	+30
350,000	0.171	2.5	295,000	+16

(a) Variation of cost with effectiveness was estimated.

(b) As scaled: 2.5 hours tap-to-tap.

The discrepancies are large. Although they do not detract from the estimating procedures used by Swindell-Dressler, they do illustrate that the estimates may not agree well with limited amounts of data obtained for actual installations. The indicated value for g is especially distant from the g derived from Battelle's assumed effectiveness factor and is probably quite distorted by the pretest at E = 2.5, which is an unusual case. According to the parameters, the industry data are reasonably coherent. Before NAPCA could justify extensive use of estimating procedures, those procedures would have to be verified by similar direct comparisons. The result is not conclusive, but it serves as a warning against use of untested estimates such as the effectiveness-scaling estimate applied by Battelle in this case.

From the Swindell-Dressler estimates, the cost of air-pollution controls for electric-arc steelmaking (at standard throughput and effectiveness) appeared to be about 30 to 50 cents per ton of steel. The industrial data, however, indicated costs ranging as high as $2 per ton of steel, even with throughput standardized to holding capacity. Two of the pretests were poor, and indicate that the estimates may be low or that the industry figures are not to comparable bases.

The normalization of throughput data to a tap-to-tap time of 2.5 hours (as a reference point) is based on the idea that air-pollution controls must be designed and operated to accommodate emission peaks for batch processes. The duration of off-peak periods is of importance secondary to the rate of emissions during the peaks.

Basic Oxygen Steelmaking

Swindell-Dressler prepared estimates of control costs for three sizes of new basic oxygen furnaces and for three types of control on each size of furnace. These data were normalized for operation of one of two side-by-side furnaces connected to a single system, and throughput scaling was based on a tap-to-tap time of 1 hour and an operating year of 8000 hours. Scaling for changes in effectiveness was based on Swindell-Dressler estimates in the case of wet scrubbers and electrostatic precipitators, and was estimated by Battelle in the case of baghouses. Table V-5 gives the data, the models, and all pretesting results.

The six available pretests showed moderate to large discrepancies, which fell to both sides of the Swindell-Dressler estimates. Although the estimates indicated reference-point costs of just under $1 per ton of steel, data reported by steel companies were not coherent and showed a range of 60 cents to $1.90 per ton.

A combined model determined for wet scrubbers and electrostatic precipitators appeared to represent the Swindell-Dressler estimates within ±20 percent. Pretesting of this combined model was attempted via regression analysis of the six sets of pretest data (all refer to either wet scrubbers or electrostatics), but the resulting model parameters were not coherent. (This means the reported data do not fit an orderly surface.)

TABLE V-5. DATA, MODELING RESULTS, AND PRETESTS FOR BASIC OXYGEN FURNACES

Control Used	Cost per Year	Throughput, million tons	Grains Dust at Outlet	Effectiveness Coefficient
		Data: As Expanded		
High-energy wet scrubbers	$ 774,000	0.8	0.125	0.4
	821,000	0.8	0.05	1.0
	895,000	0.8	0.02	2.5
	1,332,000	1.6	0.125	0.4
	1,413,000	1.6	0.05	1.0
	1,540,000	1.6	0.02	2.5
	1,845,000	2.4	0.125	0.4
	1,958,000	2.4	0.05	1.0
	2,135,000	2.4	0.02	2.5
Electrostatic precipitators	616,000	0.8	0.125	0.4
	678,000	0.8	0.05	1.0
	746,000	0.8	0.02	2.5
	1,107,000	1.6	0.125	0.4
	1,218,000	1.6	0.05	1.0
	1,340,000	1.6	0.02	2.5
	1,553,000	2.4	0.125	0.4
	1,708,000	2.4	0.05	1.0
	1,879,000	2.4	0.02	2.5
Fabric filters	448,000[a]	0.8	0.125	0.4
	498,000	0.8	0.05	1.0
	553,000	0.8	0.02	2.5
	848,000	1.6	0.125	0.4
	942,000	1.6	0.05	1.0
	1,046,000	1.6	0.02	2.5
	1,220,000	2.4	0.125	0.4
	1,354,000	2.4	0.05	1.0
	1,503,000	2.4	0.02	2.5

Models Obtained by Regression Analysis of Above Data

For wet scrubbers: $C = \$987,000 \times T^{.79} \times E^{.08}$

For electrostatic precipitators: $C = \$819,000 \times T^{.84} \times E^{.10}$

For fabric filters: $C = \$611,000 \times T^{.91} \times E^{.11}$

For combined data representing scrubbers and electrostatics: $C = \$899,000 \times T^{.82} \times E^{.09}$

Results of Pretesting

Reported Industry Data			Calculated	Percent
Cost	Throughput[b]	Effectiveness	Cost	Discrepancy
$1,495,000	2.04	1	$1,733,000	-16
$2,180,000	1.60	1	1,413,000	+35
$1,200,000	2.20	0.5	1,479,000	-23
$1,694,000	0.88	2.5	964,000	+48
$1,270,000	2.00	1	1,467,000	-16
$2,260,000	1.92	2.5	1,551,000	+31

(a) Variation of cost with effectiveness was estimated.

(b) As scaled: 1 hour tap-to-tap.

The principle that a good model will represent a group of cases better than it will represent the individuals within the group is borne out by the model for basic oxygen furnaces. Whereas the average absolute discrepancy of pretests was 28 percent on an individual basis, the discrepancy for the combined figures was 14 percent. Additional pretests should continue to lower this combined discrepancy. If they do, the primary model may be valid for projections despite poor fit to any given case.

Open-Hearth Steelmaking

The Swindell-Dressler estimates for air-pollution control costs for three sizes of existing (not new) open-hearth furnaces and for three types of control systems were scaled, modeled, and pretested as shown in Table V-6. Scaling overall was based on a shop of six furnaces with separate collectors, and a tap-to-tap time of 8 hours was assumed. Specific cost versus effectiveness factors were prepared by Swindell-Dressler for wet scrubbers and for electrostatic precipitators, and Battelle estimated the scaling factor for changed effectiveness of fabric filters. Cost-effectiveness data reported by steel companies permitted four pretests.

As in the case of electric-arc steelmaking, there was an opportunity for direct analysis of some of the data furnished by sources within the steel industry. The last three pretests shown in Table V-6 refer to use of electrostatic precipitators, and the coherent discrepancies illustrate the internal consistency of these data. Solution of three equations in three unknowns gave the following preliminary model:

$$C = \$1,133,000 \times T^{.73} \times E^{.22} \quad .$$

The corresponding model from Swindell-Dressler estimates was:

$$C = \$1,045,000 \times T^{.66} \times E^{.09} \quad .$$

Comparison of these models indicates moderately good agreement for the factor A and for the sensitivity exponent for throughput (T), but as in the case of the electric-arc furnace there was a difference between the theoretical and reported exponents denoting sensitivity to effectiveness. This was regarded as additional evidence that there is general agreement between the mathematics of the model and the industrial facts, and also as evidence that the theoretical determination of sensitivity to effectiveness may give incorrect estimates.

Steelmaking: Overview

The three principal steelmaking processes are all batch processes. It was found that in dealing with these processes, values for throughput must be scaled arbitrarily. A dust-collection system must be designed to trap the dust at the time of peak emission; thus its cost depends upon the amount of emission per unit time over what may be a short part of the steelmaking cycle. Because variations in practice and in the type of steel being made can lead to a two-fold or greater disparity in tap-to-tap time in any

TABLE V-6. DATA, MODELING RESULTS, AND PRETESTS FOR OPEN-HEARTH FURNACES

Control Used	Cost per Year	Throughput, million tons	Grains Dust at Outlet	Effectiveness Coefficient
		Data: As Expanded		
High-energy wet scrubbers	$ 732,000	0.36	0.05	0.25
	776,000	0.36	0.125	0.4
	846,000	0.36	0.2	1.0
	1,750,000	1.2	0.05	0.25
	1,855,000	1.2	0.125	0.4
	2,023,000	1.2	0.2	1.0
	3,862,000	3.6	0.05	0.25
	4,093,000	3.6	0.125	0.4
	4,463,000	3.6	0.2	1.0
Electrostatic precipitators	490,000	0.36	0.125	0.4
	534,000	0.36	0.05	1.0
	582,000	0.36	0.02	2.5
	1,079,000	1.2	0.125	0.4
	1,176,000	1.2	0.05	1.0
	1,282,000	1.2	0.02	2.5
	2,230,000	3.6	0.125	0.4
	2,430,000	3.6	0.05	1.0
	2,647,000	3.6	0.02	2.5
Fabric filters	353,000[(a)]	0.36	0.125	0.4
	406,000	0.36	0.05	1.0
	467,000	0.36	0.02	2.5
	829,000	1.2	0.125	0.4
	954,000	1.2	0.05	1.0
	1,097,000	1.2	0.02	2.5
	1,857,000	3.6	0.125	0.4
	2,136,000	3.6	0.05	1.0
	2,455,000	3.6	0.02	2.5

Models Obtained by Regression Analysis of Above Data

For wet scrubbers: $C = \$1,774,000 \times T^{.72} \times E^{.10}$

For electrostatic precipitators: $C = \$1,045,000 \times T^{.66} \times E^{.09}$

For fabric filters: $C = \$844,000 \times T^{.72} \times E^{.15}$

Results of Pretesting

Reported Industry Data			Calculated	Percent
Cost	Throughput	Effectiveness	Cost	Discrepancy
$2,242,000	1.8	1.6	$2,840,000	-27
1,706,000	1.52	1.6	1,437,000	+16
1,776,000	1.98	0.8	1,608,000	+ 9
2,340,000	2.7	1	2,013,000	+14

(a) Variation of cost with effectiveness was estimated.

type of steelmaking furnace, standardization is required. The throughput is properly determined by multiplying tonnage capacity (per batch) by nominal operating hours per year (usually 8000), and dividing by a characteristic tap-to-tap time. For a 150-ton electric furnace, the tap-to-tap time might be 90 minutes in a modern reinforcing-bar plant, and 4 to 5 hours for the manufacture of aircraft-quality alloy steel with a two-slag practice. Using the typical tap-to-tap time of 2.5 hours for both cases gives the same value for throughput.

$$150 \times \frac{8000}{2.5} = 480,000 \text{ tons per year}$$

in each shop, although actual throughputs would be 800,000 tons per year for the rebar plant and as low as 240,000 tons per year for the alloy-steel plant. The dust-collection systems probably would not differ very much.

The average absolute discrepancy between pretest data and steelmaking cost models was almost 24 percent, but the aggregate error for the 14 pretests was only 11 percent. This result supports the general conclusion that modeling is more accurate for a group of installations than for individual installations within the group.

Teeming of Molten Steel

Swindell-Dressler prepared no cost estimates for teeming-fume controls, and steel-industry sources submitted no information. Lack of suitable applied technology can account for this, because the only teeming-fume collectors known to Battelle are either whole-shop exhaust systems or hoods applied to continuous-casting facilities. Both types of equipment are rare among the information sources used to date.

Slab and Billet Conditioning

The Swindell-Dressler data and the primary models derived from them are presented for scarfing operations in Table V-7. Two control systems were studied at two different capacities, thus the data "forced" the model and no relevant test of the modeling procedure was made. Volume-throughput ratings were converted to tonnage-throughput ratings via an arbitrary scaling factor of 10 tons per year per cfm gas throughput.

The cost data submitted by steel companies showed an annualized cost of $95,000 per year for scarfer fume collectors applicable to a throughput of 1.6 million tons of steel annually. For this installation, the outlet loading is controlled to 0.02 grain per cubic foot; thus the effectiveness ratio is about 2.5. Direct pretesting was not feasible because the cfm-throughput rating on this equipment was not given. More information is needed on the relationship between costs, air-volumes handled, and steel-scarfing capacity to permit better scaling of data.

TABLE V-7. DATA AND MODELING RESULTS FOR SCARFING MACHINES

Control Used	Cost per Year	Throughput, million tons	Grains Dust at Outlet	Effectiveness Coefficient
		Data: As Expanded		
High-energy wet scrubbers	$ 86,000	0.5	0.125	0.4
	101,000	0.5	0.05	1.0
	122,000	0.5	0.02	2.5
	144,000	1.0	0.125	0.4
	168,000	1.0	0.05	1.0
	203,000	1.0	0.02	2.5
Electrostatic precipitators	70,000	0.5	0.125	0.4
	83,000	0.5	0.05	1.0
	98,000	0.5	0.02	2.5
	104,000	1.0	0.125	0.4
	123,000	1.0	0.05	1.0
	145,000	1.0	0.02	2.5

Models Obtained by Regression Analysis of Above Data

For wet scrubbers: $C = \$170,000 \times T^{.74} \times E^{.19}$

For electrostatic precipitators: $C = \$123,000 \times T^{.57} \times E^{.18}$

Results of Pretesting

None

Hot-Rolling and Hot-Working of Steel

A number of hot-strip mills, especially the larger and faster ones, have dust collectors at the finishing stands to pick up the fine particles of scale that are thrown into the air during rolling. Other uses of air-pollution controls in hot-working may also exist, but no data or cost information was furnished on any of these installations. It was concluded that the release of suitable data was blocked because cost information on pollution-control equipment was not separable from rolling costs.

SECTION VI

FINDINGS AND RECOMMENDATIONS

In the cost/effectiveness studies of Phase I, Battelle and Swindell-Dressler sought to develop and pretest methods to be used by NAPCA in preparing national and regional analyses of the costs of controlling air pollution from steelworks operations. This effort led to a clarification of some of the specific problems now facing NAPCA's Division of Economic Effects Research. In this Section, the problems are categorized, methods for overcoming them are suggested, and a specific program of future work toward the required analyses is proposed.

There are 37 different process segments as listed by Battelle for purposes of economic study (Table V-1). To complete the research required by the Congress, costs for controlling air pollution from each of these process segments must be determined at several levels of effectiveness. The main determinant of future economic study methods, and the primary determinant of the degree of accuracy to be obtained in those studies, is the degree to which the individual air-pollution problems within each process segment have been solved in the practical sense. Three technological categories may be identified:

Category A. Process segments for which practical air-pollution controls exist and have in fact been applied in a number of steel plants

Category B. Process segments for which technically reasonable methods of air-pollution control may exist, but for which few or no specific applications have been made in the plants

Category C. Process segments for which practical air-pollution controls have not yet been developed.

Table VI-1 lists the 38 process segments according to Battelle's present opinion of their approximate categorization (under the above criteria) for future studies.

The assignments of process segments to technological categories as given in Table VI-1 are intended as a guide to the content of future economic studies. The judgments upon which these assignments are based are subject to a number of exceptions. For example:

(1) Assignment to Category A is based on Battelle's understanding of present-day standards of satisfactory emission control. The standards are ill-defined and subject to change.

(2) Assignment to Category A does not apply for certain variants in the processes; e.g., for the manufacture of highly-fluxed blast-furnace sinter.

(3) Assignment to Category B implies technical and economic practicality: a relative state which these studies may disprove for any given case.

(4) Technical studies now in progress may (hopefully) alter the assignments to Category C over a short span of time.

Accordingly, the assignments should be regarded as approximate and subject to both exception and change.

TABLE VI-1. PROCESS SEGMENTS OF THE INTEGRATED IRON AND STEEL INDUSTRY, CATEGORIZED ACCORDING TO THE STATE OF PROGRESS IN AIR-POLLUTION CONTROL

Category A: Practical air-pollution controls exist and are applied to many emission sites; segments amenable to statistical analysis.

Coke-oven seals
Coke quenching
Coke-oven gas system
Coke handling

Flux handling
Hot metal handling
Steelmaking furnaces

Hot-dip coating
Electrocoating

Sintering
Pelletizing
Blast-furnace charging
Blast-furnace smelting

Conditioning of slabs, billets
Hot rolling
Acid pickling
Cold rolling

Plant-waste incineration

Category B: Practical means of controlling air pollution may exist but are not widely applied; segments amenable to engineering estimation.

Coal receiving and storage
Coal handling
By-products recovery

Scrap charging
Steel teeming

Cleaning and degreasing
Painting
Cold-dip coating

Ore and flux receiving and storage
Ore and flux handling
Pigging of iron

Soaking, reheating, etc.
Primary rolling of ingots

Category C: Practical means of controlling air pollution do not exist.

Coke-oven charging
Coke-oven pushing

Fluid-fuel boilers
Solid-fuel boilers

Casting and flushing
Slag disposal (from ironmaking)

Scrap preparation

Criteria for Planning Future Phases

Battelle suggests that planning of future cost and/or economic studies, beginning with those of Phase II, should be oriented to the technological categorization presented in Table VI-1. The proposed criteria for planning of further studies are as follows.

(1) They should deal with the facts and costs of actual existing control installations first, and with speculative costs and uncertain technologies last.

This criterion permits NAPCA to concentrate first on the actual expenditures by steelmakers, which Congress wants to know and which the steelmakers consider to be an important input to policy formation. This criterion also emphasizes that NAPCA and NAPCA's contractors shall seek to understand present conditions as fully as possible before projecting costs into areas of little or no hard knowledge.

(2) The studies should be based as fully as possible upon the actual cost/effectiveness experiences of the steel companies for present installations.

This criterion emphasizes the primary accuracy of measured costs as compared to engineering estimates of cost. In dealing with process segments from Categories B and C where estimates are essential to cost studies, confidence will be improved if scaling exponents (b and g in the model described in Section V) may be estimated by analogy between the uncertain situations and previously studied plant situations.

(3) The studies should be based on nationally dispersed input samples, and regional estimates should be produced by projection.

(4) In no instance should projection be used to estimate control costs for a specific process segment in a specific plant.

Whereas the use of samples drawn from the entire nation should probably produce better overall accuracy than the use of a smaller sample from within a region, reasoning from the general cost model to any specific case is not valid. Such argument would be equivalent to sewing a suit of clothes for the average U. S. male and then expecting it to fit most people.

(5) Continuing effort should be made to enlarge the active cooperation and the direct assistance of steel companies in preparing the analyses.

The steelmakers have shown willingness (as a group) to help keep these studies on firm ground technically and economically. However, as individual companies they are concerned that their competitive positions may suffer through too much disclosure. Battelle is convinced that much more disclosure is desirable, and that study plans should be of such a nature as to encourage further disclosure.

Organization and Objectives of Phases II, III, and IV

In accord with the five criteria proposed above, Battelle recommends the continuing cost-effectiveness studies for control of air pollution from steel plants should be organized in three phases that need not be completely consecutive. Overlap is acceptable, but the completion of Phase II should precede the final efforts on Phase III, and the completion of Phase III should precede the final estimates of Phase IV. The three proposed phases, as suggested by Battelle, will deal with the process segments in their technological categories:

> Phase II would be a statistical modeling study of process segments in Category A.
>
> Phase III would be a mixed statistical and estimation study of process segments in Category B.
>
> Phase IV would be a cost study of the process segments in Category C, conducted entirely by estimation.

In suggesting the above phasing, Battelle hopes to obtain the most-needed information as early as possible, and then to use this information to improve the validity of the studies that have weaker foundations. It is also intended that the passage of time (as the research proceeds) will bring technical growth that will tend to promote process segments from Category C to Category B, and from Category B to Category A. Overall, the proposed phasing is a route chosen for minimum uncertainty of results.

Phase II: Study of Process Segments Now Largely Controlled

The suggested methodology for Phase II is to assemble all possible data describing air-pollution control costs, process throughputs, and control effectiveness for the 18 process segments to be studied. Using the general mathematical model developed in Phase I, researchers should reduce these data by regression analysis. The result of data-processing will be 18 or more cost models, at least one for each process segment under study. Using the current AISI Iron and Steel Works Directory of the United States and Canada and other sources, NAPCA may then compile an inventory of population for each process segment, by regions. Application of the models will project costs for the entire population of all 18 process segments, regionally and as a total for the nation, at any selected level of effectiveness. The modeling process will also suggest the mean effectiveness now attained where controls have in fact been installed.

Assembly of Data

Lack of availability of large amounts of steel industry cost information (the first step of the methodology described above) was a defect in the conduct of Phase I. NAPCA, for its part, acted from the point of view that it is advantageous to industry for these cost studies to be made in advance of the setting of air-quality standards. NAPCA stated that the steel industry has a stake and an obligation in helping to avoid arbitrary air-quality decisions by giving these studies a foundation of economic understanding. Indeed, a review of testimony will show that steelmakers and other industrialists requested this approach when the Congress was considering air-quality legislation.

The steel industry, for its part, did not foresee that intensive cost studies would intrude into their cost and production records. Such records have long been considered a part of steelmakers' private business knowledge, to be held secret for purely business reasons from competitors, unions, suppliers, and government alike. Indeed, the

AISI-sponsored exchanges of current technical operating data are considered by steel companies to be an advanced form of cooperation. Additionally, the steel industry has just been through a period of annoyance at the hands of the popular press; much of it based on sensational interpretation of water-quality data released in confidence (without control costs) to Federal and state agencies. From this viewpoint, assurances that individual data-offerings will not be applied to individual abatement actions tend to be received with skepticism.

Battelle suggests that these studies can be performed in a manner that is palatable to all concerned. It is clearly possible to characterize the cost of air-pollution controls with respect to process throughput and control effectiveness on a regional or national scale.without perusal of private data. NAPCA or NAPCA's contractors can in fact do the job without ever seeing the numbers. Battelle's methodology during Phase I has been based all along on the reduction of data to descriptive mathematical expressions, and it is the expressions, not the data, that are important. Regression analysis, properly applied, is an automatic procedure for the digestion and precise description of moderate to large masses of coherent data.

It follows that these studies, and particularly those of Phase II, are not in the least affected if data are supplied and processed without examination by NAPCA or NAPCA's contractors. The examination of individual data, like the examination of individual beans, can serve no useful purpose except the culling-out of spoiled ones. And just as beans are culled by electric-eye, the data can be culled while it is processed simply by applying statistical tests of coherence during processing. This procedure may be a trivial safeguard, for the most intelligent examination of the data is the examination made by the accountants and engineers who prepare it.

Battelle recommends that the steel industry representatives and NAPCA representatives should arrange mutually satisfactory ways to get data into analytical operations without disclosing the data as such. Mechanically, the best route is probably for the companies to punch all of the data into conventional 80-column data-processing cards. A single card can contain all of the data required for a single air-pollution control installation:

Columns 1-5: Number of process segment for which data are provided

Columns 6-10: Year of most recent expansion, rebuild, or installation

Columns 11-20: Process throughput, tons of product or intermediate produced per normal year

Columns 21-25: Number of process units, for batch processes

Columns 26-50: Batch capacities, in tons (separated by commas)[*]

---

[*] Or other qualifying data, such as sinter basicity, if use of expanded mathematical models is contemplated.

Columns 51-60: Overall capital cost of air-pollution controls

Columns 61-70: Direct operating cost of air-pollution controls

Columns 71-80: Effectiveness of controls – form of data entry varies with process segment.

Cards of this kind can be brought or mailed to a meeting, or submitted to a disinterested trustee for accumulation.

Data Processing

Accumulated data cards could form a large deck. This deck should then be sorted to condense separate decks for each of the process segments or other subdivisions (there are three subdivisions of steelmaking, for example). Decks for each process segment may then be processed through individual programs which will perform the scaling operations and the estimation of the effectiveness coefficient, E. This intermediate step will result in a new deck with only the process segment or sub-segment number and the input values of C, T, and E on each card.

The secondary decks may then be fed directly into the regression-analysis program. This program may be chosen from a number of alternative forms, or prepared specially for the work of Phase II. Computer commands causing the taping or other output of inbound data should be deleted, and tests of significance may be added to guard against wild data entering and biasing the operations. Because regression analysis is performed rapidly by computers, all conceivable models and options should be tried and compared. Specifically, there are several options in the analysis of batch processes, according to whether the sizes of individual process units are considered to be important or not. Also, the effect of nominal sinter basicity should be tried as an expansion of the basic model. Only a few days would be required to exhaust the possibilities so that the original and secondary data decks may be destroyed.

Security procedures for data processing may be arranged easily. One or more observers representing the steel industry could be present for the entire data-processing session, and could bring the data to the processing center and take them away or destroy them at the end of the job. When the computer is set up for preprocessing and analysis operations, the observers may catalog which data-storage units are connected to the system. When the work is finished, the observers may supervise the clearing of all data-storage areas, and verify the clearances by simple tests. Of course, the industry observers should be qualified systems engineers, preferably with experience on computers similar to the one used.

Application of Cost Models

In cases where alternative modeling forms have been used to process input data during the analytical step, the key to selection among the results is the reported "index of determination", sometimes denoted as ρ^2 (rho squared). This parameter denotes mathematically how well each model fits the data it is supposed to represent. An interim report for Phase II could be prepared at the completion of analyses to present the models obtained, to establish choices between alternative forms, and to examine the overall validity of the procedure as given by the indices of determination.

It is conceivable that at this point some changes of direction may be required. Process segments represented by marginal amounts of data may be cited for gathering of additional data and reprocessing. Others may prove to be poorly fitted in spite of generous data supply, and these process segments may be relegated to analysis by other approaches in Phase III or IV.

Where coherent models are obtained, which should be in the large majority of cases, they may be applied directly to the characterization of regional and national control costs. For this purpose, an inventory of process segment throughputs is required for each area studied. An inventory of physical facilities such as sinter plants, blast furnaces, coke ovens, and steelmaking furnaces and mills is available from the AISI in the directory previously cited. Conversion of this inventory into throughputs may be accomplished entirely by estimation, or (preferably) with the help of the steel companies themselves. A convenient way to assign throughputs would be to utilize the pertinent AISI operating reports, or appropriate figures from them. These reports have been made available to Battelle. Effectiveness data are not required; NAPCA will stipulate levels of effectiveness for some studies, and may use the average from the original data in other cases such as the determination of present costs and effectiveness.

The elements of population, together with effectiveness values or stipulations, could be entered on cards for computer processing. For each process segment, a computer would be used to apply the model to each element of the population in turn, determining a cost and accumulating it into regional or national totals as required. As indicated in the criteria presented early in this Section, the individual costs thus computed would have no validity or usefulness of themselves, thus the computer output would properly be confined to totals only.

Completion of the regional and national projections would end Phase II. In planning this work, the essence of success is to arrange for data transfers satisfactory to both the steel industry and NAPCA.

Phases III and IV: Study of Other Process Segments

The successful arrangement and accomplishment of data transfers in Phase II could become the basis for continued cooperation between NAPCA and the steel industry. If so, the work of Phases III and IV would be greatly facilitated.

In Phase III, the object would be to combine cost-effectiveness data for limited numbers of actual installations, exponents of sensitivity determined from the experiences of Phase II, and straightforward engineering estimation in a three-way approach to the modeling of air-pollution controls in Category B. This work could also lead to the formation of mathematical cost models, somewhat similar to those formed in Phase I from Swindell-Dressler's estimates.

Inasmuch as "blind" data processing is inapplicable to Phase III, a certain amount of reliance would be placed on companies who do have controls installed on Category B process segments to step forth and describe their experiences to the contractor. There would be no need to identify sources, but the actual data would be of interest in the steps prior to modeling. The process of engineering estimation in Phase III could be improved if the estimators were invited to use specific plants as bases for estimation. Estimates would turn out better, on average, if reviewed by plant engineers. At least six to eight inputs to modeling of each process segment should be used. Where three actual installations may be studied, the number of estimates required would be from three to five. Modeling, analysis, and application would be as in Phase II, with the recognition of greater uncertainty in the answers.

In Phase IV, pure estimation is to be applied to characterization of possible costs for controlling situations where truly practical controls do not exist. There can be no attempt to determine what the costs will actually be. One can only hope to determine the minimum attainable costs for existing technology. An example will illustrate the procedure.

In the case of the charging and pushing of coke ovens, true controls do not exist and the segments are assigned to Category C. To attain control, some apparent alternatives seem to be to (1) totally enclose the coke ovens or (2) make coke in some other way. Although neither of these alternatives may appear to be truly practical, they may be evaluated to the nearest order of magnitude – that is, we can estimate whether each will cost \$1, \$10, or \$100 per ton of coke. For some kinds of alternatives slightly more precise determinations may be possible. The approximate costs may be estimated, and after consideration of a number of alternatives, one or two may stand out as least expensive. The cost for the least-expensive solution considered is the temporary cost answer for that process segment.

It should be apparent that many heads should be brought to bear on this kind of estimation. In Phase IV, NAPCA might find it efficient to sponsor seminars for specialists in the particular processes being studied. At these seminars, the problems of estimation would be outlined, and the group would generate and edit a list of ideas, selecting those which are seemingly "least impractical" to be tested by estimation. The regional and national costs resulting from Phase IV will necessarily be inaccurate, and may be useful mainly for assigning research priorities. However, there is always the chance that one or more potentially practical ideas may come from the process of examining existing impractical possibilities in a serious manner.

APPENDIX A

LIST OF STEELWORKS BY TYPES

PART I. INTEGRATED STEELWORKS

(These combine the operations of smelting iron ore, conversion of iron to steel, and shaping of raw steel into saleable forms.)

Company, Plant, and Location	Number of Blast Furnaces
Alan Wood Steel Company	
Swede Furnaces, Swedeland and Ivy Rock, Pennsylvania	2
Armco Steel Corporation	
Ashland, Kentucky	3
Houston, Texas	1
Hamilton and Middletown, Ohio	3
Bethlehem Steel Corporation	
Bethlehem, Pennsylvania	5
Sparrows Point, Maryland	10
Lackawanna, New York	7
Johnstown, Pennsylvania	5
CF&I Steel Corporation	
Pueblo, Colorado	4
Crucible Steel Company of America	
Midland, Pennsylvania	3
Detroit Steel Corporation	
Portsmouth, Ohio	2
Ford Motor Company	
Dearborn, Michigan	3
Granite City Steel Company	
Granite City, Illinois	2
Inland Steel Company	
Indiana Harbor, East Chicago, Illinois	8
Interlake Steel Corporation	
Chicago and Riverdale, Illinois	2
International Harvester Company	
Wisconsin Steel, South Chicago, Illinois	3
Jones & Laughlin Steel Corporation	
Aliquippa, Pennsylvania	5
Pittsburgh, Pennsylvania	5
Cleveland, Ohio	2
Kaiser Steel Corporation	
Fontana, California	4
Lone Star Steel Company	
Lone Star, Texas	1
McLouth Steel Corporation	
Trenton, Michigan	2
National Steel Corporation	
Weirton, West Virginia	4
Great Lakes, Ecorse, Michigan	4
Republic Steel Corporation	
Youngstown, Ohio	4
Warren, Warren and Niles, Ohio	1
Massillon-Canton, Ohio	2
Cleveland, Ohio	6
Buffalo, New York	2
South Chicago, Illinois	1
Gulfsteel, Gadsden, Alabama	2
Sharon Steel Corporation	
Roemer, Farrell, Pennsylvania	2

PART I. (Continued)

Company, Plant, and Location	Number of Blast Furnaces	Company, Plant, and Location	Number of Blast Furnaces
United States Steel Corporation		Wheeling-Pittsburgh Steel Corporation	
Duquesne, Pennsylvania	5	Monessen, Pennsylvania	3
Edgar Thomson, Braddock, Pennsylvania	6	Steubenville, Ohio	5
Homestead, Rankin and Munhall, Pennsylvania	5	Youngstown Sheet and Tube Company	
Gary, Indiana	12	Campbell, Campbell, Ohio	4
South Chicago, Illinois	11	Brier Hill, Youngstown, Ohio	2
Fairless, Fairless Hills, Pennsylvania	3	Indiana Harbor, East Chicago, Indiana	3
Fairfield District, Jefferson County, Alabama	8		
Geneva, Utah	3		
National, McKeesport, Pennsylvania	4		
Lorain, Ohio	5		
Youngstown, Ohio	4		
Duluth, Minnesota	2		

PART II. SECONDARY STEELWORKS

(These combine the operations of steelmaking - usually by remelting scrap - and shaping of raw steel into saleable forms.)

Company, Plant, and Location	Number of Melting Furnaces
Alco Products, Incorporated	
Latrobe, Pennsylvania	2
Allegheny Ludlum Steel Corporation	
Brackenridge, Pennsylvania	15
Dunkirk and Watervliet, New York	12
Ferndale, Michigan	8
Special Metals, New Hartford, New York	9
Allison Steel Manufacturing Company	
Tempe, Arizona	2
American Compressed Steel Corporation	
Cincinnati, Ohio	1
Armco Steel Corporation	
Baltimore, Maryland	6
Butler, Pennsylvania	7
Kansas City, Missouri	3
Sand Springs, Oklahoma	1
Torrance, California	3
Atlantic Steel Company	
Atlanta, Georgia	2
Babcock & Wilcox Company (The)	
Beaver Falls, Pennsylvania	7
Baldwin-Lima-Hamilton Corporation	
Burnham, Pennsylvania	7
Bethlehem Steel Corporation	
Steelton, Pennsylvania	4
Los Angeles, Vernon, California	3
Seattle, Washington	2
Border Steel Rolling Mills, Incorporated	
Vinton, Texas	2
Borg-Warner Corporation	
New Castle, Indiana	4
Chicago Heights, Illinois	2
Braeburn Alloy Steel Division, Continental Copper and Steel Industries, Incorporated	
Braeburn, Pennsylvania	3
Byers Company, A.M.	
Ambridge, Pennsylvania	2
Cabot Corporation	
Pampa, Texas	1
Cameron Iron Works, Incorporated	
Houston, Texas	19
Carpenter Steel Company (The)	
Reading, Pennsylvania	8
New England, Bridgeport, Connecticut	2
Ceco Corporation (The)	
Lemont, Illinois	3
Milton, Pennsylvania	3
C F & I Steel Corporation	
Roebling, Burlington County, New Jersey	3
Columbia Tool Steel Company	
Chicago Heights, Illinois	2
Continental Steel Corporation	
Kokomo, Indiana	5
Copperweld Steel Company	
Aristoloy, Warren, Ohio	8
Crucible Steel Company of America	
Syracuse, New York	10

PART II. (Continued)

Company, Plant, and Location	Number of Melting Furnaces
Cyclops Corporation	
Mansfield, Ohio	8
Bridgeville, Pennsylvania	10
Titusville, Pennsylvania	3
Driver Company, Wilbur B.	
Newark, New Jersey	5
Eastern Stainless Steel Corporation	
Baltimore, Maryland	7
Edgewater Steel Company	
Oakmont, Pennsylvania	1
Erie Forge & Steel Corporation	
Erie, Pennsylvania	2
Etiwanda Steel Producers, Incorporated	
Etiwanda, California	2
Finkl & Sons Company, A.	
Chicago, Illinois	2
Firth Sterling, Incorporated	
McKeesport, Pennsylvania	7
Florida Steel Corporation	
Tampa, Florida	3
Croft, North Carolina	2
Harper Company, H. M.	
Morton Grove, Illinois	2
Harsco Corporation	
Harrisburg, Pennsylvania	3
Hawaiian Western Steel Limited	
Ewa, Hawaii	1
Heppenstall Company	
Pittsburgh, Pennsylvania	2
Philadelphia, Pennsylvania	6
Intercoastal Steel Corporation	
Chesapeake, Virginia	1
Interlake Steel Corporation	
Wilder, Kentucky	3
Jessop Steel Company	
Washington, Pennsylvania	6
Owensboro, Kentucky	2
Jones & Laughlin Steel Corporation	
Warren, Michigan	6
Jorgensen Company, Earle M.	
Seattle, Washington	2
Joslyn Mfg. and Supply Company	
Fort Wayne, Indiana	3
Judson Steel Corporation	
Emeryville, California	3
Kankakee Electric Steel Company	
Kankakee, Illinois	2
Kentucky Electric Steel Company	
Coalton, Kentucky	1
Keystone Steel and Wire Company	
Peoria, Illinois	5
Knoxville Iron Company	
Knoxville, Tennessee	3
Laclede Steel Company	
Alton, Illinois	2
Latrobe Steel Company	
Latrobe, Pennsylvania	5
Le Tourneau, Inc. (R. G.)	
Longview, Texas	3
Lukens Steel Company	
Coatesville, Pennsylvania	9
Mesta Machine Company	
West Homestead, Pennsylvania	5
New Castle, Pennsylvania	4

PART II. (Continued)

Company, Plant, and Location	Number of Melting Furnaces
Mississippi Steel Corporation	
Flowood, Mississippi	2
National Forge Company	
Irvin, Pennsylvania	3
North Star Steel Company	
St. Paul, Minnesota	1
Northwest Steel Rolling Mills, Inc.	
Seattle, Washington	2
Northwestern Steel & Wire Company	
Sterling, Illinois	5
Oregon Steel Mills	
Portland, Oregon	3
Owen Electric Steel Company of South Carolina	
Cayce, South Carolina	2
Pacific States Steel Corporation	
Union City, California	4
Phoenix Steel Corporation	
Phoenixville, Pennsylvania	5
Claymont, Delaware	7
Pollak Steel Company (The)	
Marion, Ohio	1
Porter Company, Inc., H. K.	
Connors, Birmingham, Alabama	3
Huntington, West Virginia	2
Roanoke Electric Steel Corporation	
Roanoke, Virginia	3
Roblin Steel Corporation	
Dunkirk, New York	3
Simonds Steel Division, Wallace Murray Corporation	
Lockport, New York	5
Soulé Steel Company	
Long Beach, California	1
Southern Electric Steel Company	
Birmingham, Alabama	2
Southwest Steel Rolling Mills	
Los Angeles, California	2
Structural Metals, Inc.	
Seguin, Texas	2
Texas Steel Company	
Fort Worth, Texas	4
Timken Roller Bearing Company (The)	
Canton, Ohio	9
Union Electric Steel Corporation	
Carnegie and Harmon Creek, Pennsylvania	1
United States Steel Corporation	
Johnstown, Pennsylvania	3
Torrance, California	4
Vasco Metals Corporation	
Monroe, North Carolina	7
Latrobe, Pennsylvania	11
Monaca, Pennsylvania	1
Washburn Wire Company	
Phillipsdale, Providence County, Rhode Island	4
Washington Steel Corporation	
Houston, Pennsylvania	2
Wickwire Brothers, Inc.	
Cortland, New York	2

PART III. STEEL PROCESSING PLANTS

(These obtain raw or semifinished steel from other plants for processing to saleable shapes. List is edited by omission of plants with no hot-fabricating operations.)

Company, Plant, and Location	Number of Reheat Furnaces
Allegheny Ludlum Steel Corporation	
West Leechburg, Pennsylvania	1
American Chain & Cable Company, Inc.	
Page, Monessen, Pennsylvania	2
Arkansas Steel Corporation	
Magnolia, Arkansas	Unknown
Armco Steel Corporation	
Ambridge, Pennsylvania	4
Zanesville, Ohio	4
Babcock & Wilcox Company (The)	
Milwaukee, Wisconsin	5
Bethlehem Steel Corporation	
Lebanon, Pennsylvania	1
Burns Harbor, Porter County, Indiana	12
South San Francisco, California	3
Borg-Warner Corporation	
Chicago, Illinois	2
Franklin, Pennsylvania	1
Copperweld Steel Company	
Shelby, Ohio	4
Glassport, Pennsylvania	2
Cyclops Corporation	
Pittsburgh, Pennsylvania	10
Hoster Investment Company	
Oklahoma City, Oklahoma	2
Jersey Shore Steel Company	
South Avis, Pennsylvania	1
Keystone Steel and Wire Company	
Chicago Heights, Illinois	1
Lake Erie Rolling Mill, Inc.	
Tonawanda, New York	1
Lockhart Iron & Steel Company	
Vulcan Iron, McKees Rocks, Pennsylvania	3
Michigan Seamless Tube Company	
South Lyon, Michigan	1
Rosenberg, Texas	2
Missouri Rolling Mill Corporation	
St. Louis, Missouri	2
Northern Steel Incorporated	
Medford, Massachusetts	1
Phoenix Manufacturing Company	
Joliet, Illinois	3
Poor & Company, Inc.	
Troy, New York	2
Republic Steel Corporation	
Elyria, Ohio	2
Cleveland, Ohio	2
Roblin Steel Corporation	
North Tonawanda, New York	1
Tredegar Company	
Richmond, Virginia	2
United States Steel Corporation	
Irvin, Dravosburg, Pennsylvania	5
Gary Sheet & Tin, Gary, Indiana	5
Pittsburgh, California	1
Ellwood, Pennsylvania	11
Fairless, Fairless Hills, Pennsylvania	1
Gary Tube, Gary, Indiana	3
South, Worcester, Massachusetts	1
Cleveland, Ohio	3
Joliet, Illinois	5
Wheeling-Pittsburgh Steel Corporation	
Benwood, West Virginia	1

PART IV. IRONWORKS

(These are based upon the operations of smelting iron from iron ore, or ferrous alloys for use in steelmaking.)

Company, Plant, and Location	Number of Coke Ovens	Number of Blast Furnaces
Interlake Steel Corporation		
Erie, Pennsylvania	58	1
Toledo, Ohio	151	2
Jackson Iron and Steel Company (The)		
Jackson, Ohio	None	1
Lavino and Company, E. J.		
Sheridan, Pennsylvania	None	1
Lynchburg, Virginia	None	2
National Steel Corporation		
Hanna, Buffalo, New York	None	4
Republic Steel Corporation		
Troy, New York	None	1
Thomas, Birmingham, Alabama	65	2
Shenango, Incorporated		
Neville Island, Pennsylvania	105	2
Sharpsville, Pennsylvania	None	2
Tonawanda Iron Division, American Radiator and Standard Sanitary Corporation		
North Tonawanda, New York	None	1
United States Pipe and Foundry Company		
Birmingham, Alabama	240	3
United States Steel Corporation		
Cleveland, Ohio	None	2
Woodward Iron Company		
Woodward, Alabama	256	4
Rockwood, Tennessee	44	2

PART V. COKE PLANTS

(These are based upon the conversion of coal to coke and the recovery of organic byproducts from the coking process. Beehive plants are omitted as are plants producing foundry coke.)

Company, Plant, and Location	Number of Coke Ovens
Alabama Byproduct Corporation	
Tarrant, Alabama	203
Allied Chemical Corporation	
Ashland, Kentucky	196
Buffalo, New York	120
Ironton, Ohio	168
Citizens Gas & Coke Utility	
Indianapolis, Indiana	168
Connecticut Coke Company	
New Haven, Connecticut	70
Donner-Hanna Coke Corporation[a]	
Buffalo, New York	200
Eastern Gas & Fuel Associates	
Philadelphia, Pennsylvania	74
Empire Coke Company	
Holt, Alabama	60
Indiana Gas & Chemical Corporation	
Terre Haute, Indiana	60
Koppers Company, Inc.	
Kearny, New Jersey	125
St. Paul, Minnesota	65
Milwaukee Solvay Div. Pickands Mather and Company	
Milwaukee, Wisconsin	200
Sharon Steel Corporation	
Fairmont, West Virginia	60
United States Steel Corporation[b]	
Clairton, Pennsylvania	1375

(a) Owned jointly by Republic Steel and National Steel.

(b) Includes alloy blast furnace and rolling mills.

COST/EFFECTIVENESS STUDY OF STEELWORKS AIR-POLLUTION CONTROLS

SUMMARY A -- CHARGING OF COAL TO BYPRODUCT COKE OVENS

I. Identification

Company: ____________________ Data entered by: ____________________

II. Capacity of Coking Operations Represented by This Summary

Typical annual coke production, net tons, wet = ____________________

Number of batteries = ______ Number of ovens = ______

III. Description of Equipment and Activities Represented

On the reverse side of this sheet, briefly describe equipment and/or activities used to control smoke and dust during charging of coke ovens. Use block diagrams to illustrate sequential equipment; omit numerical data.

IV. Estimated Installed Capital Cost of Pollution-Control Equipment

Exclude land, and apparatus not specifically used to control pollution.

Include equipment, installation, engineering, research, start-up, maintenance tools and facilities, inventories, and incremental costs for changes in production equipment to accommodate pollution-control devices.

Estimated installed capital cost = $____________

Year of start-up: ______; Annual escalation has averaged about ______%

V. Estimated Operating Cost of Air-Pollution Control System

Exclude depreciation, taxes, interest, insurance, and all other fixed costs.

Include labor, supervision, maintenance, utilities, materials, major repair allowances, and direct effects upon production cost. Credit materials reclaimed and increases in life of equipment.

Estimated annual operating cost = $____________

Man-hours direct labor/year = _______ Credits total $(__________)

VI. Estimated Overall Effectiveness of Controls Represented by This Summary

Check one:

_____ Air pollution from charging is completely suppressed or contained

_____ Controls described do a thorough job and meet public standards fully

_____ Controls are based on best available technology but are not adequate

_____ Other: ____

____

For ducted systems, indicate range of outlet grain loadings observed: from _____ grains to _____ grains particulates per cubic foot.

COST/EFFECTIVENESS STUDY OF STEELWORKS AIR-POLLUTION CONTROLS

SUMMARY B -- PREVENTION OF LEAKAGE FROM END DOORS OF COKE OVENS

I. Identification

Company:____________________ Data entered by:______________________________

II. Capacity of Coking Operations Represented by This Summary

Typical annual coke production, net tons, wet = ______________________________

Number of batteries = ______ Number of ovens = ______

III. Description of Equipment and Activities Represented

On the reverse side of this sheet, briefly describe equipment and activities used to minimize leakage from end doors of the coke ovens. Omit numerical data.

IV. Estimated Installed Capital Cost of Pollution-Control Equipment

Exclude land, and apparatus not specifically used to prevent leakage.

Include equipment and tools, installations, engineering, research, inventories, and changes in production equipment to accommodate leakage-control programs or devices.

Estimated installed capital cost = $________________

Year of installation:______; Annual escalation has averaged ______%

V. Estimated Operating Cost of Air-Pollution Control Program

Exclude depreciation, taxes, interest, insurance, and all other fixed costs.

Include labor, supervision, maintenance, utilities, materials, major repair allowances, and direct effects upon production cost. Credit any noticed increase in yield of gas and byproducts.

Estimated annual operating cost = $______________

Man-hours direct labor/year = ______ Credits total $(__________)

VI. Estimated Overall Effectiveness of Controls Represented by This Summary

Check one:

_____ Leakage from oven doors is completely eliminated

_____ Control program described is thorough and meets public standards fully

_____ Control program is based on best available technology but is inadequate

_____ Other:____

____

COST/EFFECTIVENESS STUDY OF STEELWORKS AIR-POLLUTION CONTROLS

SUMMARY C -- PUSHING OF COKE FROM BYPRODUCT COKE OVENS

I. Identification

Company:________________________ Data entered by:____________________________

II. Capacity of Coking Operations Represented by This Summary

Typical annual coke production, net tons, wet = ______________________________

Number of batteries = ________ Number of ovens = ______________

III. Description of Equipment and Activities Represented

On the reverse side of this sheet, briefly describe equipment and/or activities used to control smoke and dust during pushing of coke ovens. Use block diagrams to illustrate sequential equipment; omit numerical data.

IV. Estimated Installed Capital Cost of Pollution-Control Equipment

Exclude land, and equipment not specifically used to control pollution

Include equipment, installation, engineering, research, start-up, maintenance tools and facilities, inventories, and incremental costs for changes in production equipment to accommodate pollution-control devices.

Estimated installed capital cost = $_________________

Year of start-up: ______; Annual escalation has averaged about______%

V. Estimated Operating Cost of Air-Pollution Control System

Exclude depreciation, taxes, interest, insurance, and all other fixed costs

Include labor, supervision, maintenance, utilities, materials, major repair allowances, and direct effects upon production cost. Credit materials reclaimed and increases in life of equipment.

Estimated annual operating cost = $_________________

Man-hours direct labor/year = ________ Credits total $(__________)

VI. Estimated Overall Effectiveness of Controls Represented by This Summary

Check one:

_____ Air pollution from pushing is completely suppressed or contained

_____ Controls described do a thorough job and meet public standards fully

_____ Controls are based on best available technology but are not adequate

_____ Other:____

For ducted systems, indicate range of outlet grain loadings observed: from _____ grains to _____ grains particulates per cubic foot.

COST/EFFECTIVENESS STUDY OF STEELWORKS AIR-POLLUTION CONTROLS

SUMMARY D -- QUENCHING OF COKE MADE IN BYPRODUCT COKE OVENS

I. Identification

Company:__________________________ Data entered by:____________________________

II. Capacity of Coking Operations Represented by This Summary

Typical annual coke production, net tons, wet = ______________________

Number of batteries = _________ Number of ovens = _________

III. Description of Equipment and Activities Represented

On the reverse side of this sheet, briefly describe equipment and/or activities used to control escape of dust during quenching of byproduct coke. Use simple diagrams to illustrate methods; omit numerical data.

IV. Estimated Installed Capital Cost of Pollution-Control Equipment

Exclude land, and apparatus not specifically used to control pollution.

Include equipment, installation, engineering, research, start-up, maintenance tools and facilities, inventories, and incremental costs for changes in production equipment to accommodate pollution-control devices.

Estimated installed capital cost = $______________________

Year of start-up:______; Annual escalation has averaged about ______%

V. Estimated Operating Cost of Air-Pollution Control System

Exclude depreciation, taxes, interest, insurance, and all other fixed costs.

Include labor, supervision, maintenance, utilities, materials, major repair allowances, and direct effects upon production cost. Credit materials reclaimed or conserved and increases in life of equipment.

Estimated annual operating cost = $_________________

Man-hours direct labor/year = _______ Credits total $(__________)

VI. Estimated Overall Effectiveness of Controls Represented by This Summary

Check one:

_____ Air pollution from quenching is completely suppressed or contained

_____ Controls described do a thorough job and meet public standards fully

_____ Controls are based on best available technology but are not adequate

_____ Other:____
____

If measurements have been made, indicate pounds coke dust lost per ton of coke quenched (other than to sump)_____

COST/EFFECTIVENESS STUDY OF STEELWORKS AIR-POLLUTION CONTROLS

SUMMARY E -- CONTAINMENT OF FUMES AND VAPORS FROM COKE-OVEN BYPRODUCTS

I. Identification

Company:____________________ Data entered by:______________________________

II. Capacity of Coking Operations Represented by This Summary

Typical annual coke production, net tons, wet = ____________________

Number of batteries = ______ Number of ovens = __________

III. Description of Equipment and Activities Represented

On the reverse side of this sheet, briefly describe equipment and/or activities used to control escape of fumes and vapors from the byproduct systems of the coke plant. Use simple diagrams to illustrate methods; omit numerical data.

IV. Estimated Installed Cost of Pollution-Control Equipment

Exclude land, and apparatus not specifically used to control pollution

Include equipment, installation engineering research, start-up, maintenance tools and facilities, inventories, and incremental costs for changes in production equipment to accommodate pollution-control devices.

Estimated installed capital cost = $____________________

Year if start-up; Annual escalation has averaged about _____ percent

V. Estimated Operating Cost of Air-Pollution Control System

Exclude depreciation, taxes, interest, insurance, and all other fixed costs.

Include labor, supervision, maintenance, utilities, materials, major repair allowances, and direct effects upon production cost. Credit materials reclaimed or conserved and increases in life of equipment.

Estimated annual operating cost = $________________

Man-hours direct labor/year = ______ Credits total $(_________)

VI. Estimated Overall Effectiveness of Controls Represented by This Summary

Check one:

_____ Fumes and vapors from the byproduct system are completely contained

_____ Controls described do a thorough job and meet public standards fully

_____ Controls are based on best available technology but are not adequate

_____ Other:____

____

COST/EFFECTIVENESS STUDY OF STEELWORKS AIR-POLLUTION CONTROLS

SUMMARY F -- DESULFURIZATION OF COKE-OVEN GAS PRIOR TO DISTRIBUTION

I. Identification

Company:__________________________ Data entered by: __________________________

II. Capacity of Coke-Oven Gas System Described in This Summary

Typical annual production of coke-oven gas for all uses, millions of cubic feet at 1 atmosphere pressure and 60 F = ______________________________.

Percent used to underfire ovens = ______ Percent sold = ______________________

Percent used in mixture with other fuel gases = ______________

III. Description of Desulfurization Equipment and Process

On the reverse side of this sheet, briefly outline the steps taken to remove hydrogen sulfide from raw coke-oven gas prior to distribution. Use block diagrams to illustrate sequential equipment; omit numerical data.

IV. Estimated Installed Capital Cost of Pollution-Control Equipment

Exclude land, and equipment not specifically used to desulfurize gas.

Include equipment, installation, engineering, research, start-up, maintenance tools and facilities, inventories, and incremental costs for changes in production equipment (e.g. booster pumps) to accommodate desulfurizing apparatus.

Estimated installed capital cost = $_______________________

Year of start-up:__________ Annual escalation has averaged about _____ percent

V. Estimated Operating Cost of Gas Desulfurization System

Exclude depreciation, taxes, interest, insurance, and all other fixed costs

Include labor, supervision, maintenance, utilities, materials, major repair allowances, and direct effects upon gas distribution cost. Credit sulfur values reclaimed if any and increases in life of equipment.

Estimated annual operating cost = $____________________

Man-hours direct labor/year = _________ Credits total $(_________)

VI. Overall Effectiveness of Desulfurization Represented by This Summary

State total sulfur or hydrogen sulfide present in unmixed coke-oven gas after desulfurization, in units convenient to you:____________________________

____

COST/EFFECTIVENESS STUDY OF STEELWORKS AIR-POLLUTION CONTROLS

SUMMARY G -- UNLOADING, STORAGE, AND RECLAIMING OF IRON ORES AND FLUXES

I. Identification

Company:____________________ Data entered by: ____________________

II. Capacity of Bulk Handling Operations Represented by This Summary

Typical annual receipts/consumption of natural and processed iron ores and limestone or dolomite for blast-furnace and sinter plant use, net tons, natural basis = ____________________

Percentage of receipts arriving during lake navigation season only = __________

Briefly describe unloading/stocking/reclaiming system if not based on ore bridges:____________________

III. Description of Equipment and Activities Represented

On the reverse side of this sheet, briefly describe measures taken to suppress and/or collect handling dusts from iron ores and fluxes. Omit numbers.

IV. Estimated Installed Capital Cost of Pollution-Control Equipment

Exclude land, and equipment not specifically applied to pollution control.

Include equipment, installation, engineering, research, start-up, maintenance tools and facilities, inventories, and incremental costs for changes in production equipment to accommodate pollution-control devices.

Estimated installed capital cost = $______________

Year of start-up:______; Annual escalation has averaged about _____ percent

V. Estimated Operating Cost of Air-Pollution Control Systems

Exclude depreciation, taxes, interest, insurance, and all other fixed costs.

Include labor, supervision, maintenance, utilities, materials, major repair allowances, and direct effects upon production cost. Credit materials reclaimed or conserved and increases in life of equipment.

Estimated annual operating cost = $______________

Man-hours direct labor/year = _________ Credits total $(_________)

VI. Estimated Overall Effectiveness of Controls Represented by This Summary

Check one:

_____ Air pollution from bulk handling is completely suppressed or contained

_____ Controls described do a thorough job and meet public standards fully

_____ Controls are based on best available technology but are not adequate

_____ Other:____________________

____

COST/EFFECTIVENESS STUDY OF STEELWORKS AIR-POLLUTION CONTROLS

SUMMARY H -- SINTERING OF FINE ORES, FLUXES, AND RECYCLED DUSTS

I. Identification

Company: ________________________ Data entered by: ___________________________

II. Capacity of Sintering Operations Represented by This Summary

Typical annual sinter production, net tons = _______________

Basicity:_____% at B/A = ______; _____% at B/A = ______

Number of sintering strands = _______

III. Description of Equipment and Activities Represented

On the reverse side of this sheet, briefly describe equipment used to control dust in all sectors of the sintering operation. Use simple block diagrams to illustrate sequential equipment; omit numerical data.

IV. Estimated Installed Capital Cost of Pollution-Control Equipment

Exclude land, and apparatus not specifically used to control pollution

Include equipment, installation, engineering, research, start-up, maintenance tools and facilities, inventories, and incremental costs for changes in production equipment to accommodate pollution-control devices.

Estimated installed capital cost = $__________________

Year of start-up:______ Annual escalation has averaged about ______%

V. Estimated Operating Cost of Air-Pollution Control System

Exclude depreciation, taxes, interest, insurance, and all other fixed costs

Include labor, supervision, maintenance, utilities, materials, major repair allowances, and direct effects upon production cost. Credit materials reclaimed and increases in life of equipment.

Estimated annual operating cost = $____________________

Man-hours direct labor/year = ______ Credits total $(__________)

VI. Estimated Overal Effectiveness of Controls Represented by This Summary

Range of outlet grain loadings observed for main exhaust stacks, _____ to ______ grains particulates per cubic foot.

Range of outlet grain loadings observed for cooler/handling exhausts, _____ to ______ grains particulates per cubic foot

Check one:

_____ Air pollution from sintering is completely suppressed or contained

_____ Controls described do a thorough job and meet public standards fully

_____ Controls are based on best available technology but are not adequate

_____ Other: ____

____

COST/EFFECTIVENESS STUDY OF STEELWORKS AIR-POLLUTION CONTROLS

SUMMARY I -- PELLETIZING OF IRON-ORE CONCENTRATES

I. Identification (do not disclose pellet company name)

Reporting Company:________________________ Data entered by:________________

II. Capacity of Pelletizing Operations Represented by This Summary

Typical annual pellet shipments, net tons = ________________

Induration furnaces: Number = __________ Type: ____________

III. Description of Equipment and Activities Used to Control Air Pollution

On the reverse side of this sheet, briefly describe equipment used to control dust in pelletizing, induration, and handling operations. Use simple block diagrams to illustrate sequential equipment. Omit numerical data and controls applied during mining and concentration of ores.

IV. Estimated Installed Capital Cost of Pollution-Control Equipment

Exclude land, and apparatus not specifically used to control pollution

Include equipment, installation, engineering, research, start-up, maintenance tools and facilities, inventories, and incremental costs for changes in production equipment to accommodate pollution-control devices.

Estimated installed capital cost = $__________

Year of start-up; ______ Annual escalation has averaged about _____ percent

V. Estimated Operating Cost of Air-Pollution Control Systems

Exclude depreciation, taxes, interest, insurance, and all other fixed costs

Include labor, supervision, maintenance, utilities, materials, major repair allowances, and direct effects upon production or shipping cost. Credit materials reclaimed and increases in life of equipment.

Estimated annual operating cost = $________________

Man-hours direct labor/year = ______ Credits total $(__________)

VI. Estimated Overall Effectiveness of Controls Represented by This Summary

Range of outlet grain loadings observed for induration furnaces, ______ to ______ grains particulates per cubic foot.

Check one:

_____ Air pollution from pelletizing and pellet handling or loading is completely suppressed or contained

_____ Controls described do a thorough job and meet public standards fully

_____ Controls are based on best available technology but are not adequate

_____ Other: ____

COST/EFFECTIVENESS STUDY OF STEELWORKS AIR-POLLUTION CONTROLS

SUMMARY J -- CHARGE PREPARATION AND CHARGING OF BLAST FURNACES

I. Identification

Company: ________________________ Data entered by: ____________________________

II. Capacity of Ironmaking Operations Represented by This Summary

Typical annual hot metal production, net tons = _________________

Number of blast furnaces = ______ Typical coke/NTHM = _______ pounds

Overall burden is roughly ______ percent iron ore ______ percent pellets

______ percent sinter ______ percent other

III. Description of Equipment and Activities Represented

On the reverse side of this sheet, briefly describe equipment and/or activities used to control dust in the stockhouses and furnace tops.* Exclude bleeders as a source; omit numerical data.

IV. Estimated Installed Capital Cost of Pollution-Control Equipment

Exclude land, and apparatus not specifically used to control pollution.

Include equipment, installation, engineering, research, start-up, maintenance tools and facilities, inventories, and incremental costs for changes in production equipment to accommodate pollution-control devices.

Estimated installed capital cost = $______________________

Year of start-up: _______ Annual escalation has averaged about ______%

V. Estimated Operating Cost of Air-Pollution Control System

Exclude depreciation, taxes, interest, insurance, and all other fixed costs.

Include labor, supervision, maintenance, utilities, materials, major repair allowances, and direct effects upon production cost. Credit materials reclaimed and increases in life of equipment.

Estimated annual operating cost = $_________

Man-hours direct labor/year = _________ Credits total $(_________)

VI. Estimated Overall Effectiveness of Controls Represented by This Summary

Check one:

_____ Air pollution from charging is completely suppressed or contained

_____ Controls described do a thorough job and meet public standards fully

_____ Controls are based on best available technology but are not adequate

_____ Other: ____

____

---

*The exact scope of this Summary is: discharge of raw materials to stockhouse bins or pockets; stockhouse operations including screening, weighing, and disposal of undersize; materials hoisting to furnace top; discharge of skips and operation of distributor; opening of small and large bells. Cost of normal sealing bells and hoppers is not considered a control cost.

COST/EFFECTIVENESS STUDY OF STEELWORKS AIR-POLLUTION CONTROLS

SUMMARY K -- PREVENTION OR CONTAINMENT OF SULFUROUS FUMES FROM IRONMAKING SLAG

I. Identification

Company: ____________________ Data entered by: ____________________________

II. Capacity of Ironmaking Operations Represented by This Summary

Typical annual hot metal production, net tons = ____________

Number of furnaces = ______ Typical slag/NTHM = ______ pounds

III. Description of Equipment and Activities Represented

On the reverse side of this sheet, briefly describe methods of slag disposal and means employed to control emission of hydrogen sulfide, sulfur dioxide, and other sulfurous gases during flushing, handling, and disposal or accumulation of slag.

IV. Estimated Installed Capital Cost of Pollution-Control Equipment

Exclude land, and apparatus not specifically used to control pollution.

Include equipment, installation, engineering, research, start-up, maintenance tools and facilities, inventories, and incremental costs for changes in production equipment to accommodate pollution-control devices.

Estimated installed capital cost = $_________

Year of start-up: ______ Annual escalation has averaged about ______ percent

V. Estimated Operating Cost of Air-Pollution Control Systems

Exclude depreciation, taxes, interest, insurance, and all other fixed costs.

Include labor, supervision, maintenance, materials, utilities, major repair allowances, and direct effects upon production cost. Credit materials reclaimed (sulfur values?) and increases in life of equipment.

Estimated annual operating cost = $_________

Man-hours direct labor/year = ______ Credits total $(_________)

VI. Estimated Overall Effectiveness of Controls Represented by This Summary

Check one:

_____ Sulfurous gases from ironmaking slag are wholly suppressed or contained

_____ Controls described do a thorough job and meet public standards fully

_____ Controls are based on best available technology but are not adequate

_____ Other: ____

____

COST/EFFECTIVENESS STUDY OF STEELWORKS AIR-POLLUTION CONTROLS

SUMMARY L --MELTING, REFINING, FINISHING, AND TAPPING OF STEEL

I. Identification

Company: ________________________ Data entered by: ____________________________

II. Capacity of Steelmaking Operations Represented by This Summary

Typical annual crude steel production, net tons = __________________

Number of furnaces = _______ Type of furnaces = ___________________

III. Description of Equipment and Activities Represented

On the reverse side of this sheet, briefly describe equipment and/or activities used to control air-pollution from steelmaking operations. Use block diagrams to illustrate sequential equipment; omit numerical data but for BOF shops state how many furnaces operate at once.

IV. Estimated Installed Capital Cost of Pollution-Control Equipment

Exclude land, and apparatus (such as waste-heat boilers) not specifically used to control air pollution.

Include equipment, installation, engineering, research, start-up, maintenance tools and facilities, inventories, and incremental costs for changes in production equipment to accommodate pollution-control devices.

Estimated installed capital cost = $____________________

Year of start-up: _______ Annual escalation has averaged about _____ percent

V. Estimated Operating Cost of Air-Pollution Control System

Exclude depreciation, taxes, interest, insurance, and all other fixed costs.

Include labor, supervision, maintenance, utilities, materials, major repair allowances, and direct effects upon production cost. Credit materials reclaimed and increases in life of equipment.

Estimated annual operating cost = $_________

Man-hours direct labor/year = _______ Credits total $(_________)

VI. Estimated Overall Effectiveness of Controls Represented by This Summary

Check one:

_____ Air pollution from steelmaking operations is completely suppressed or contained

_____ Controls described do a thorough job and meet public standards fully

_____ Controls are based on best available technology but are not adequate

_____ Other: ____

____

Range of outlet grain loadings observed for stacks = ______ grains to ______ grains particulates per cubic foot.

COST/EFFECTIVENESS STUDY OF STEELWORKS AIR-POLLUTION CONTROLS

SUMMARY M -- TEEMING OF MOLTEN STEEL

I. Identification

Company: ____________________ Data Entered by: ____________________________

II. Capacity of Teeming Operation Represented by This Summary

Typical annual tonnage of steel poured, net tons = ________________________________

_____ Continuous casting; _____ Ingot practice, type: ________________________

III. Description of Equipment and Activities Represented

On the reverse side of this sheet, briefly describe equipment and/or activities used to control smoke, dust, and fume during teeming of steel. Use block diagrams to illustrate sequential equipment; omit numerical data.

IV. Estimated Installed Capital Cost of Pollution-Control Equipment

Exclude land, and apparatus not specifically used to control pollution.

Include equipment, installation, engineering, research, start-up, maintenance tools and facilities, inventories, and incremental costs for changes in production equipment to accommodate pollution-control devices.

Estimated installed capital cost = $_________________

Year of start-up: ________ Annual escalation has averaged about _____ percent

V. Estimated Operating Cost of Air-Pollution Control Systems

Exclude depreciation, taxes, interest, insurance, and all other fixed costs.

Include labor, supervision, maintenance, utilities, materials, major repair allowances, and direct effects upon production cost. Credit materials reclaimed and increases in life of equipment.

Estimated annual operating cost = $__________

Man-hours direct labor/year = ______ Credits total $(__________)

VI. Estimated Overall Effectiveness of Controls Represented by This Summary

Check one:

_____ Air pollution during teeming is completely suppressed or contained

_____ Controls described do a thorough job and meet public standards fully

_____ Controls are based on best available technology but are not adequate

_____ Other: ____

____

If a ducted exhaust system is used to control teeming fumes, give range of outlet grain loadings observed: ______ grains to ______ grains particulates per cubic foot.

COST/EFFECTIVENESS STUDY OF STEELWORKS AIR-POLLUTION CONTROLS

SUMMARY N -- CONDITIONING OF SLAB, BLOOM, OR BILLET SURFACES

I. Identification

Company: ______________________ Data entered by: _______________________________

II. Capacity of Conditioning Operations Represented by This Summary

Typical annual throughput of semifinished steel, net tons = _____________________

Type of conditioning: _____ grinding_____ scarfing by_____ hand; _____ machine

III. Description of Equipment and Activities Represented

On the reverse side of this sheet, briefly describe equipment and/or activities used to control airborne dusts during conditioning of steel. Use block diagrams to illustrate sequential equipment; omit numerical data.

IV. Estimated Installed Capital Cost of Pollution-Control Equipment

Exclude land, and apparatus not specifically used to control pollution.

Include equipment, installation, engineering, start-up, research, maintenance tools and facilities, inventories, and incremental costs for changes in production equipment to accommodate pollution-control devices.

Estimated installed capital cost = $____________________

Year of start-up; _______ Annual escalation has averaged about _____ percent

V. Estimated Operating Cost of Air-Pollution Control Systems

Exclude depreciation, taxes, interest, insurance, and all other fixed costs.

Include labor, supervision, maintenance, utilities, materials, major repair allowances, and direct effects upon production cost. Credit materials reclaimed and increases in life of equipment.

Estimated annual operating cost = $_________

Man-hours direct labor/year = ______ Credits total $(_________)

VI. Estimated Overall Effectiveness of Controls Represented by This Summary

For ducted systems, indicate range of outlet grain loadings observed: from ______ grains to ______ grains particulates per cubic foot.

Check one:

_____ Air pollution from conditioning is completely suppressed or contained

_____ Controls described do a thorough job and meet public standards fully

_____ Controls are based upon best available technology but are not adequate

_____ Other: ____

____

COST/EFFECTIVENESS STUDY OF STEELWORKS AIR-POLLUTION CONTROLS

SUMMARY O -- HOT-WORKING OF STEEL BY FORGING OR ROLLING

I. Identification

Company: ______________________________ Data entered by: _____________________

II. Capacity of Steelworking Operations Represented by This Summary

Typical annual throughput of semifinished steel, net tons = _________________________

Type of operation: __________ Typical piece weight ___________________tons

III. Description of Equipment and Activities Represented

On the reverse side of this sheet, briefly describe equipment and/or activities used to control airborne dust and fume during hot-working of steel. Use block diagrams for illustration of sequential equipment; omit numerical data,

IV. Estimated Installed Capital Cost of Pollution-Control Equipment

Exclude land, and apparatus not specifically used to control pollution.

Include equipment, installation, engineering, research, start-up, maintenance tools and facilities, inventories, and incremental costs for changes in production equipment to accommodate pollution-control devices.

Estimated installed capital cost = $________________________

Year of start-up: ______ Annual escalation has averaged about _____ percent

V. Estimated Operating Cost of Air-Pollution Control System

Exclude depreciation, taxes, interest, insurance, and all other fixed costs.

Include labor, supervision, maintenance, utilities, materials, major repair allowances, and direct effects upon production cost. Credit any materials reclaimed and increases in life of equipment.

Estimated annual operating cost = $________________________

Man-hours direct labor/year = _______ Credits total $(__________)

VI. Estimated Overall Effectiveness of Controls Represented by This Summary

For ducted systems, indicate range of outlet grain loadings observed: from _____ grains to _____ grains particulates per cubic foot.

Check one:

_____ Air pollution from hot-working is completely suppressed or contained

_____ Controls described do a thorough job and meet public standards fully

_____ Controls are based upon best available technology but are not adequate

_____ Other: ____

____

APPENDIX C FOR FINAL ECONOMIC REPORT ON COST ANALYSES

for

A SYSTEMS ANALYSIS STUDY OF THE
INTEGRATED IRON AND STEEL INDUSTRY
(Contract No. PH 22-68-65)

to

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
NATIONAL AIR POLLUTION CONTROL ADMINISTRATION
DIVISION OF ECONOMIC EFFECTS RESEARCH

May 15, 1969

COSTS AND PERFORMANCE OF CONTROL SYSTEMS AND CONTROL EQUIPMENT

(Sub-Contract Tasks)

by

P. R. Klauss, Principal Investigator, Economic

P. L. Sieffert, Principal Investigator, Technical

J. F. Skelly, Sub-Contract Task Force Director

Swindell-Dressler Company
A Division of Pullman Incorporated
441 Smithfield Street
Pittsburgh, Pa. 15222

TABLE OF CONTENTS

APPENDIX C

Summary and Conclusions C- 1
Primary Categorization of Costs C- 2
The General Structure of Capital Costs C- 2
Categorization Schemes C- 4
The General Problem of Capital Cost Estimating C- 6
The General Structure of Operating Costs C- 8
The General Problems of Estimating Operating Costs C- 9

Costs of Control Systems C- 10
  Effect on Cost of Multiple Furnace Installations C- 11
  Special Problems Encountered When Installing New Control Equipment in Existing Plants C- 11
  Data Sources, Procedure, Precision of Results C- 13
  Alternate Systems C- 15
  Sinter Plants C- 17
  Pelletizing Plants C- 24
  Coke Oven C- 29
  Blast Furnace C- 30
  Basic Oxygen Furnace C- 32
  Open Hearth Furnace C- 36
  Electric Arc Furnaces C- 40
  Scarfing C- 45
  HCL Pickling Line C- 48
  Cold Rolling Mill C- 50
  Power Plant Boilers C- 52
  Sample Calculation - Operating Cost C- 55
  Method of Determining Exhaust Gas Volume C- 56
  Capital Cost Breakdown C- 58
  Gaseous Pollutants C- 65
  Area Ventilation and Emission Control C- 65
  Effect of Efficiency Specifications Greater than Current Legal Requirements C- 68
    Performance Equations C- 69

Theoretical Performance Variables C- 71
Control System Cost Changes C- 73
Conclusions C- 93

Factors Affecting Gas Cleaner Performance C- 96
Gas Volume Changes C-109
Pressure Drop C-110
Dust Loading C-110
Condition of Particulate C-111
Temperature and Humidity C-117
Adaptability to Removal of Gaseous Pollutants C-122

SUMMARY AND CONCLUSIONS

In this appendix, the cost of air pollution control equipment is estimated for various processes of the integrated iron and steel industry. Factors affecting the performance of control equipment and the effect of performance level on cost are discussed.

The purpose of the cost estimating presented here is to provide average data on the emission control cost per production unit, as an initial step in the formulation of a model for calculating the national cost of air pollution control in the industry. A technique of estimating costs for this purpose is described and used. The more detailed technique for estimating the cost of a specific installation to suit the particular conditions and specifications is not called for here. Without that detail, as outlined below, these estimates cannot and should not be used to determine the cost of control for a specific installation. An engineering analysis for that purpose, using classical estimating techniques, is available from a number of engineering firms, and should be used if the cost of control is desired for, e.g., company A's furnace B in city C.

The costs presented in the tabulations here are based on process parameters representative of average modern practice. Costs will vary from plant to plant depending on such specifics as raw material properties, details of the process as applied, product properties desired, unusual materials of construction or unusual combinations of equipment occasioned by special corrosion or abrasion conditions, details of integration of equipment into plant lay-out, etc. Typical methods of control which are, or could be, applied to the average process are cost estimated. Typical options for gas cooling are incorporated in each system; this choice, together with the average process effluent level (both gas quantity and particle concentration), determines the capacity and power ratings of equipment.

The effect on cost of unusual arrangements for combined control systems and for area ventilation is discussed. The effects on cost of unusual adaptations of equipment to existing plants and facilities are discussed.

Also presented here is an indication of the theoretically determined difference in cost for a more effective control system of the types typically used. This is not the cost of altering an existing installation, with its specific needs. These cost differences also are intended as input to the model for national costs. The development of the model with cost data from systems as used today, or as designed, will yield the ultimate tool for determining national cost, and provide an average comparison to the initial input data presented here.

Certain nominal unit costs have been established as bases for calculating operating costs. These costs will vary with monetary fluctuations over the life-span of equipment. In adjusting field data as input to the model development calculations, these costs would be normalized. Electrical energy is standardized at $50/installed HP per year (based on a standardized 330 operating days per year x 24 hours/operating day = 7,920 operating hours/year). This corresponds generally to 3/4¢/KWH for large motors. Labor cost is set at $5.00 per manhour including all welfare and fringe costs. Ratios of real, local costs to these standardized values may be used as factors for adjusting reported operating costs.

PRIMARY CATEGORIZATION OF COSTS

Many costs arise during the life span of an industrial project, from the earliest planning to the final demolition of the obsolete plant. These costs are commonly assembled into three categories:

1. Capital Costs: Cash outlays associated with planning, engineering, purchasing, construction and startup of the installation. Such costs occur only once during the life of the installation.

2. Operating Costs: Charges associated with the operation, maintenance and financing of the plant during its period of productivity. These costs are repetitive in nature, constituting a continual flow of cash away from the operating organization.

3. Demolition and Salvage Costs: Cash transactions arising while the facility is being dismantled and sold off. Some of the cash flows are expenses and some are income. The algebraic sum constitutes either the Demolition Cost or the Salvage Value depending upon the direction of the net cash flow. These items occur only once during the life of the plant, in which respect they are related to the Capital Costs in (1) above.

THE GENERAL STRUCTURE OF CAPITAL COSTS

The capital cost of any plant or facility is the sum of many separate cash payments made to suppliers of component parts, to workers of many kinds for their labor, to consultants and contractors for their services, to shippers for transportation of components to the construction site, etc. This can be expressed as

$$C_T = c_1 + c_2 + c_3 + \ldots\ldots + c_n$$

where C_T is the total capital cost and $c_1, c_2, c_3, \ldots\ldots c_n$ are individual cash payments as described above.

In most industrial projects, the total number of these payments, n, is very large. To simplify accounting and cost analysis, they are usually grouped into a relatively small number of categories. Each category contains the amounts of all payments related to some recognizable sub-division or functional aspect of the total project. If these categories are called $C_1, C_2, C_3, \ldots\ldots C_M$,

$$C_1 = c_1 + c_2 + c_3$$

$$C_2 = c_4 + c_5 + c_6 + c_7$$

$$\cdot$$
$$\cdot$$
$$\cdot$$

$$C_M = c_e + c_m + c_n$$

The sum of the categories equals the total cost, provided that each individual cash payment appears once and only once, in one and only one of the categories. That is,

$$C_T = C_1 + C_2 + C_3 + \ldots\ldots + C_M$$

In a typical situation, the total number of payments, n, might be in the range of thousands, but M, the number of cost categories, might be only 10 to 20. Various categorizing schemes may be, and have been used. Some categories may be functional in nature:

C_1 = materials cost

C_2 = field labor cost

C_3 = engineering labor cost

C_4 = freight cost

etc., etc.

In such a scheme, C_1 is the sum of all materials costs on the project while C_2 is the total cost of all labor required for field erection of all materials.

Another system of categorization can be based on major component parts of the installation. Each category would include all costs (materials, labor, freight, engineering, etc.) associated with one part of the plant.

C_1 = cost of furnaces

C_2 = cost of gas cleaning equipment

C_3 = cost of water supply system

C_4 = cost of buildings

etc., etc.

The choice of categorization scheme is usually a matter of tradition or convenience, as long as each cost item appears once and only once in the array.

As was already noted, these cost items occur only once in the life of the project. Moreover, these costs are clearly defined cash transactions, determined by market action. Unlike certain components of operating cost (discussed elsewhere), they are generally unaffected by accounting practices, tax procedures and other constraints arising from policy decisions.

The planning, engineering and construction of an industrial plant often encompasses a time span of two to four years. During these years, currency inflation may be great enough to have a significant effect on costs arising in the later phases of the overall program.

CATEGORIZATION SCHEMES

A typical categorization scheme for industrial projects divides capital costs into the following ten categories:

1. Material: This includes the purchase cost of all materials, machines, component parts, cement, structural steel, etc. which are required in the field to make up the complete operating installation. Net purchase costs are often F.O.B. point of origin.

2. Erection Labor and Supervision: This item includes wages and salaries, payroll taxes, welfare benefits, etc. for all persons employed at the construction site in the installation of the material items listed above. Some estimating procedures involve the preparation of separate estimates for the labor force and for a supervisory group of engineers. This procedure may be needed when supervision is supplied by an organization that is not responsible for employing the general construction personnel.

3. Freight: This covers the cost of transporting all of the materials from their respective points of origin to the construction site.

4. Special Tools: This cost category includes rental and transportation charges for special tools or equipment that may be needed at the construction site. Excavating equipment and large hoisting machinery are often rented for brief periods of time during a construction project because the amount of work to be done by them does not warrant their outright purchase for one job.

5. Taxes and Insurance: This covers the payment of necessary sales taxes, permits and charges for insurance protection as required during the course of the project.

6. Engineering: In this category are collected all of the costs associated with the central engineering and design aspects of the project. This includes the services of engineers and other personnel involved in the design, purchasing, and general management of the project. The costs of these services are usually calculated at a standard rate which provides for salaries, fringe benefits, occupancy, and departmental overhead. In addition, this category can logically include general overhead and fee to the central engineering organization.

7. Client Engineering and Coordination: During the design and construction of a new plant installation, the company or other organization which will operate the finished plant usually participates in the engineering and general management of design and construction. This may involve the preparation of specifications, review of design drawings, review of purchase orders, participation in development of field schedules, etc. Charges in this category should include those directly associated with the personnel involved together with an appropriate share of overhead.

8. Startup: This covers costs associated with preliminary operation and test of the new equipment in order to bring it into a condition of reasonable operating efficiency.

9. Inventory: This working capital item covers those moneys which must be tied up in inventory of raw materials, goods in process, maintenance supplies, etc.

10. Land: This covers the fair value for the land area assigned to the installation. In general, it includes not only the land occupied by processing or manufacturing equipment but also land utilized for the storage of materials and products immediately preceding and following the processing unit. In building a new installation, there is often a cost arising from the preparation of the land site. This may involve grading, filling, removal of old structures, etc., and must not be omitted from the calculation of total investment.

The total investment is the sum of all of the foregoing items. This total will not be the total payment to contractors, suppliers, and construction labor because of the presence of items 7 through 10 above. Nevertheless, all of these items (1 - 10) make up the total investment required to erect the new industrial installation and bring it into normal working condition. It is this total investment cost which enters into the cost computations elsewhere in this project.

The detailed arrangement and tabulation of individual cost items in the total as defined above can be handled in a variety of ways. The particular method selected is largely a matter of individual preferences. This may be based upon accounting practices well established in earlier projects or upon cost classifications needed for tax or operating control purposes.

In one method of tabulating costs, the costs are arranged according to the piece of equipment which is concerned; the cost of a single item of equipment would include material, erection labor and supervision, freight, engineering, etc. This leads to an estimate composed of a group of cost figures which are the total installed costs of individual pieces of equipment or of operating subsections.

Another approach to the problem is based upon functional lines. Costs are arranged in accordance with the ten categories given above. This method does not display the total installed cost of a single piece of equipment but does reveal the total cost of each function. In particular, it discloses the total cost of field labor and the total cost of engineering services. Control of these two functions is often considered to be an important matter by the managers of engineering contracts. In general, this latter scheme will be used in the present investigation, with some reduction in the number of categories, because of the generalized nature of the estimates involved.

THE GENERAL PROBLEM OF CAPITAL COST ESTIMATING

The estimator of capital costs wishes to predict the total cost, C_T, of a new installation to be designed and constructed at some later time. His principal working technique is that of extrapolation into the future, using design data on the new plant and past cost experience with similar facilities. Various estimating procedures are available, differing in the amount of work they entail, and in the accuracy of the resulting estimate. In general, the more laborious methods are needed to achieve the more accurate results. As a result, a choice must be made in any given case between estimating precision and estimating cost.

The most economical estimating procedures generally involve a direct estimate of C_T, total capital cost of a new plant, derived from a historical record of the cost of similar plants. In practice, however, such methods give very rough, imprecise estimates because the design of the new plant usually differs in major respects from its predecessors. Since many component parts of plants undergo only small changes with time, it is usually possible to obtain more precise results by making separate estimates of component costs.

Component cost estimates may be taken from historical records, or from recent market quotations. Both of these sources unavoidably contain potential errors which pass along into the total cost, C_T. The probable error in the total is a weighted average of the probable errors in all of the components. The weighting factors are based on the relative costs of the individual components, and the average is calculated as a root-mean square. As might be expected, this procedure assigns greatest importance to the most expensive components, with proportionately less emphasis on the cheaper items. In practical estimating, therefore, high-priced components must receive a great deal of attention if the final estimate is to be accurate. Smaller, inexpensive parts of the plant may be treated in a more approximate manner without seriously distrubing the total cost.

One consequence of this situation is a trend toward increasing the number of components to be estimated separately. It is argued that this will eliminate high-priced components and improve estimating accuracy because no single error will have a large weighting factor associated with it. Experienced estimators know this to be true, to some extent, but that a limit exists which cannot be passed. Even though the number of components separately estimated becomes very large, each component price estimate (however small it may be) still contains its error. The percent error in the total is always a weighted average of the percentage errors in all the component prices.

The cost of preparing an estimate increases as the number of estimated components increases. This acts to restrain the tendency toward enlargement of the number of estimated components, which is reinforced by the unavoidable total error even with a large number of components, as described in the previous paragraph.

It is important to realize that some design work must be done before the actual estimating can begin. This design work, which is expensive, must generate enough data about each component in the estimate to permit the setting of a component price. For a fully detailed estimate, the design cost may be almost as great as that needed for actual construction.

For example, a detailed estimate of the cost of foundations in an industrial plant might cover the following items:

Earthwork:	Machine Excavation
	Trench Excavation
	Hand Excavation
	Trucking and Hauling
	Backfill
Deep Foundations:	Bearing piles
	Sheet piles
	Walers
Formwork:	Buildings, mats and piers
	Spread footers
	Grade beams
	Footings
	Walls - below grade
	Walls - above grade
	Heavy equipment
	Heavy mats
	Elevated slabs
	Shored slabs and columns
	Earth slab paving
Reinforcing:	Bar
	Mesh
Miscellaneous Steel:	Anchor bolts
	Embedded steel
	Embedded railroad tracks
	Miscellaneous steel
	Checker plate and grating
Concrete:	Buildings, mats and piers
	Spread footers
	Grade beams
	Continuous footings
	Walls - above grade
	Walls - below grade
	Heavy equipment
	Heavy mats

Concrete: (continued)	Elevated slabs
	Shored slabs and columns
	Earth slab paving
	Fine grading for paving
	Batch plant
	Waterproof walls and piers
	Vapor barrier and waterstop
	Joint materials
	Color, sealer and grout
Finishes:	Steel Trowel
	Screed finish
	Brick
	Floor hardener

Separate estimates are to be made of labor and materials for each of the above items. It is evident that this array requires the making of a very detailed design together with an equally detailed compilation of historical data.

The design and estimating of a complete plan on this basis is very expensive, and will be done only under extremely competitive conditions. Moreover, this kind of analysis is not possible until a specific plant site has been selected and its characteristics have been determined.

The objectives of the present study can better be served by using a small number of components. In fact, the elaborate detail set forth above would be inappropriate because this work is not directed toward any single plant location.

THE GENERAL STRUCTURE OF OPERATING COSTS

Two classes of transactions enter into the operating cost of a manufacturing plant. One is composed of direct cash expenditures for labor, raw materials, fuel, electric power, maintenance supplies, etc. The other is a group of costs whose magnitudes are determined in part by managerial policy decisions of various kinds. Depreciation charges and general overhead burden are of this latter type.

Like capital costs, the multitude of individual operating cost items is usually arranged into a small number of categories. Some of these have been mentioned in the preceding paragraph. Since operating costs, unlike capital cost, arise continually over the many operating years of the plant's life span, they are usually collected and reported for comparatively short periods of time. Most often, the year is the time interval chosen for steady-state analysis, in order to eliminate season effects and daily fluctuations caused by minor events in plant operation. The total operating cost over this period can then be related to the total production during the same time to arrive at a useful value for the unit production cost.

Thus, if O^* is the unit production cost, O_T is the total operating cost, and W is the total number of units of production, all during a given year,

$$O^* = \frac{O_T}{W}$$

$$O_T = O_1 + O_2 + O_3 + O_4 + O_5 + \ldots\ldots + O_N$$

where O_1 = operating labor cost

O_2 = raw materials cost

O_3 = maintenance labor and materials

O_4 = electric power cost

O_5 = depreciation charges

O_6 = working capital charges

etc., etc.

During the operating life-span of a typical plant, there will be substantial changes in technology, administrative techniques, social practices, markets, state regulations, interest rates, currency values, etc. These evolutionary changes may lead to substantial modifications in the unit production cost.

THE GENERAL PROBLEMS OF ESTIMATING OPERATING COSTS

The estimation of the cost of the two types of transactions described on the previous page brings two different problems to the estimator. The first of these, the direct cash outlays for labor, maintenance,power, etc., can best be handled with the help of historical records of actual plant experience. Cost records are generally kept by operating companies for organizational cost centers based on considerations of product management, administration structure, etc. When these cost centers cover the equipment of interest to the estimator, plant records can supply directly the historical basis needed for close estimating. When the cost centers do not correspond to the operating area being examined by the estimator, the direct construction of an historical base is not possible. In that case the required cost components must be arrived at by theoretical calculations, personal recollections, intuition, etc.

Unfortunately for the present study, steel companies do not generally maintain cost centers around their pollution control activities. It is the general practice to use cost centers which include both production units and control facilities within a single perimeter. At this time there are only scattered cost data available on operating labor and maintenance for air pollution control installations in the steel industry.

The second type of component in operating cost is that whose magnitude is established by policy decisions relating to depreciation, overhead, capital charges, etc. In principle, depreciation should be based in a simple, non-controversial way on the actual life of the equipment and its ultimate salvage value. In practice, the prediction of the life and salvage value of pollution control equipment is uncertain. Operating conditions are usually severe, maintenance practices vary, and the danger of obsolescence is great. Depreciation rates therefore are strongly influenced by policy.

The allocation of corporate overhead involves even more difficult policy questions. Charges for the use of capital in control equipment require predictions of interest rates, profitability of alternative investments, and future credit rating. The estimator is clearly working in a very imprecise area when he considers these problems.

As a result, operating cost estimating is inherently uncertain and must not be expected to lead to results of high precision. The selection of optimum or preferred pollution control equipment or processes should not be based upon small differences between the operating cost of alternative designs.

COSTS OF CONTROL SYSTEMS

A control system is considered to be made up of all the items of equipment and their auxiliaries which are used solely for the general abatement of atmospheric pollution in the neighborhood of the steel works. Typically this will include a collecting hood or gas collecting pipe at the furnace, ductwork, spray cooler, dust collector, fan and motor, and stack. Included also will be structural steel, foundations, control instruments, insulation, piping, water treatment, and electric power supply facilities for the entire gas cleaning system. (Water treatment includes all those items required for gas cleaning water uses and sufficient for avoiding a water pollution problem.) Excluded are those equipment items which, while they may contribute to the functioning of pollution abatement equipment, would be used for process or economic reasons even if there were no pollution abatement requirements.

The cost of land occupied by pollution abatement equipment has not been included. It is recognized that such land has a real value but a satisfactory method for estimating it has not been established. Costs associated with preparation of the site, start-up operations and working capital are also not included. Certain portions of a control system occupy or utilize parts of steel plant buildings and, therefore, might be charged with a share of general building costs. This item has not been estimated here. In calculating operating costs no attempt has been made to allocate a portion of general overhead to control systems.

Capital and operating costs in the following tabulations are based upon collectors whose efficiency can be relied upon to produce an outlet dust loading of 0.05 grains/SCF of gas. A later section of the report contains a discussion of the relationship between cost and collection efficiency. In general, higher efficiency is more costly.

EFFECT ON COST OF MULTIPLE FURNACE INSTALLATIONS

Pollution abatement equipment becomes increasingly cheaper as the number of furnaces that can be connected to one common control system increases. The largest saving in multiple furnace situations can be realized from the alternate scheduling sequence of furnace operation. Furnace shops using arc furnaces and BOF vessels which have high and low gas emission periods seldom reach peak conditions at the same time. This is generally due to material handling which limits the furnaces in a common shop to being charged and teemed in succession. These furnaces can be lanced or blown alternately which will permit designing the multiple furnace control system for a reduced thermal capacity and reduced air volume. A single collecting system sized on this basis for two furnaces will handle approx. 1.7 times more fume than for a single furnace application and a three furnace system could be designed to handle 2.5 times more. This results in a large reduction in capital cost, although there is a loss in operating flexibility. Where flexibility is important, a design compromise is possible by using a single collector whose size will permit peak operations on all furnaces at the same time. When more than three units are to be served by a common control system, it is best to assume that several furnaces will have to be at peak load together.

The following tabulation is suggested as a rough guide for estimating the effect of combinations on capital cost; for all processes and types of control equipment.

Number of Furnaces	1	2	3
1. Separate collectors on each furnace	100%	200%	300%
2. One collector to handle peak loads on all furnaces at once.	100%	170%	250%
3. One collector to handle only one peak load at a time.	100%	140%	200%

For example, the capital cost for control equipment serving two furnaces together, with both able to run at peak loads, would be 170% of the cost for a single furnace installation.

SPECIAL PROBLEMS ENCOUNTERED WHEN INSTALLING NEW CONTROL EQUIPMENT IN EXISTING PLANTS

Existing plants can and have been revamped to accommodate modern dust collecting equipment. A grass roots plant affords the flexibility of selecting and installing cleaning equipment and duct work for maximum efficiency and minimum capital cost. Providing and adapting fume abatement equipment for an existing plant can in many cases be very expensive, especially if satisfactory land is not available for locating this new equipment. In many cases the fume collecting equipment must be located on top of the building roof which requires strenghtening all the supporting columns and trusses. A more serious situation would require placing the fans and motors at roof level. For wet scrubbers in such a case the weight due to the much higher scrubber horsepower requirements can become so costly that it might be necessary to use an inferior type of collector. The second-best collector may ultimately cost the customer more in capital expenditure, maintenance, operating cost and efficiency.

The most costly aspects of designing a new fume collection system for an operating facility often involves unusual and unorthodox arrangements of fume pickup at the furnace. This is in part due to lack of space for supports and interference with existing structures or obstructing personnel, vehicle and crane approaches. To avoid these conditions may require an alternate type of pickup at the furnaces, which, in turn, could dictate the type of apparatus used for separation of the fume and particulate matter from the gases. In one existing arc furnace shop, for example, it was most desirable to employ a direct shell tap extraction from the arc furnaces, but in this shop very little free area would then have been left for water cooled ducts, spark boxes, or cooling chambers. Consideration was given to running ducts under the teeming building but this alternative would have been extremely expensive and would have caused considerable shut-down time. Moreover, the added furnace roof loading would have required expensive revamping to support the extra weight of the water-cooled elbow. The only practical solution was to install roof-truss hoods over the furnaces. This system had the inherent disadvantage of moving 4 to 5 times the air volumes required by the direct shell tap. The additional air volume resulted in much more capital investment on fans and cleaning equipment. This fume collection system was a compromise design forced by the limitations of existing facilities. A newly designed plant could include direct shell taps on the furnaces, resulting in much less expensive equipment and in a considerable reduction in operating expense.

Limited space around an existing plant may require locating new control equipment on the roof, as previously discussed, or possibly in a location so remote as to make the duct runs much longer than would otherwise be needed. The capital cost increases because of the extra ducting and the added air friction losses. The increased static pressure requires a larger fan of greater horsepower. The result will be increased investment and higher operating costs for the life of the system.

Older control equipment at existing plants has often influenced the selection of a new type of collector system. A plant already operating with wet scrubbers will, if at all possible, try to adapt the new system to similar cleaning equipment especially if there is enough reserve built into the plant slurry system to handle the additional loading. Maintaining the same pattern of equipment will not necessarily be the best selection for the process involved and may increase the capital outlay as well as operating costs of the new installation. A grass-roots plant is not generally as much influenced by such continuity factors.

The amount of shut-down time required to install the fume collectors will add to the cost of the installation by the amount of lost production. The amount of down time that can be tolerated will influence the type, location and duct routeing of the system. Any deviation from the most direct design such as would be practical for a grass roots plant will therefore add cost to the installation.

Detailed design and estimate studies will usually be needed if cost estimates are desired for new control equipment in existing plants. The general cost data given in this report will not be reliable in such cases.

DATA SOURCES, PROCEDURE, PRECISION OF RESULTS

The primary data used in the preparation of cost estimates were taken from a number of sources. These were:

1. Estimate files of the Swindell-Dressler Company. These files ranged in age from the immediately current back to 1962. All costs were adjusted for price escalation to bring them to present levels.

2. Cost information supplied by certain steel companies relating to their own plant facilities. Such data were generally in the form of total costs for complete installations. These were adjusted for inflation by means of the same factors used on the estimate data from Swindell-Dressler files.

3. Cost information supplied by certain manufacturers of pollution control equipment. This information was presented in response to specific requests by Swindell-Dressler and came in the form of budget figures.

The Swindell-Dressler file data are detailed estimates prepared to meet the requirements of particular competitive situations. Each estimate assembled the costs for a specific location at a specific moment in time, and this was done in much detail based upon a combination of firm price quotations from suppliers and historical data about labor productivity at the location in question. Each estimate, therefore, contains cost elements which are influenced by local conditions not necessarily applicable to other plants and geographical locations. A simple compilation of these estimates would not have been adequate for the needs of the present investigation.

The data from these many particular cases have been rearranged into a more generalized form. The primary tactic used here has been that generally followed by other government agencies and students of cost estimating. This is to segregate the capital costs of the principal items of equipment in the installation and to prepare smoothed, adjusted values for these equipment items over a wide range of operating capacities. As is well known, such smoothed values usually form a straight line graph on log-log paper, with the slope of the line being related to certain characteristics of the type of equipment involved. In this study smoothed material cost data did give satisfactory linear graphs with slopes that were reasonably related to the type of equipment.

Following the practice of others in this field, the minor and bulk materials were estimated on the basis of ratios applied to the costs of the principal items. Labor costs were estimated for each principal item and bulk category by the use of standard Swindell-Dressler factors relating labor to material costs. The resulting labor figures apply to the Pittsburgh area but may be adjusted for other locations through the use of regional labor indices.

The capital costs included only facilities for loading the collected dust or sludge into trucks for transportation elsewhere. No other disposal costs or by-product values have been assigned. Central engineering costs, overheads and fees were based upon a standard sliding scale generally used by contract engineers.

It is believed that the general precision of the capital cost estimates is such that most specific plant situations will fall within ±15% of the tabulation values. In more statistical terminology it might be suggested that the standard deviation is about ±10 - 12%. It is to be expected that any specific plant location which presents unusual cost problems associated with layout, structure, power supply, etc. might fall outside these limits. In such cases a detailed plant design and estimate should be prepared if accurate capital cost data are required. As previously noted, the accuracy of operating cost values is influenced by many factors which may vary considerably from one company to another. The selection of control equipment should not be based upon small differences in operating cost estimates.

Operating cost estimates present tabulated costs for the following items:

1. Electric Power
2. Maintenance
3. Operating Labor

   Direct Operating Cost - The sum of above three items.
4. Depreciation
5. Capital Charges

The items included in Direct Operating Cost are those cost elements which are the direct cash outlays discussed on page C-8. They are, to some extent, under the control of the plant operating management. The costs assigned for Depreciation and Capital are, as noted on page C-10 based upon policy decisions not generally under the control of management at the plant operating level.

Electric energy is calculated at a standardized rate of 3/4¢ per kilowatt hour. The cost of make-up water is not included as such. Operating labor cost was calculated at the nominal value of $5.00/man hour including all welfare and fringe costs.

Maintenance is taken at a nominal cost of 4% of the total investment shown in the capital cost tables. This figure has been the subject of considerable discussion and has been retained in this analysis because it is believed to represent a reasonable value over the total life of the equipment. Most steel plant maintenance cost records do not make a separate accounting for each pollution control installation. It is, therefore, difficult to arrive at an exact, numerical evaluation of total maintenance during the life of a piece of control equipment. In actual practice, maintenance expenditures are not uniform from year to year. In many cases major maintenance outlays occur only after the passage of several years of operation. Moreover, as might be expected, maintenance costs usually increase during the service life of an item of control equipment. There have been some cases reported where major costs were experienced early in the life of a control installation. It is believed that these cases should properly be attributed to inadequate engineering rather than standard maintenance. These incidents were more common some years ago when knowledge of pollution control engineering was not as extensive as it is today. There have also been cases reported in which major modifications were made to control equipment after it had been in service for some years. Some times these episodes were caused by changes in the operating practice of the process segment which placed greater burdens on the control equipment. This type of cost is not considered to be a part of maintenance. The 4% figure is retained in this study because it is believed to represent a reasonable value for good maintenance in well designed equipment when calculated over the entire life of the installation.

In those cases where filter bag replacement represents a major maintenance cost item, the system, less bags, is given the 4% maintenance charge; and the cost in material and labor for bag replacement at a reasonable average rate (18 months for Sinter plants, 2 years for steelmaking shops) is added for the net maintenance cost listed.

Depreciation is calculated on a straight line method using total investment with an expected life of ten years. Other studies of depreciation have suggested longer service life times, but these are considered to be greater than average plant experience will confirm. Advancing technology and rising standards give importance to the factor of technical obsolescence.

Capital charges are taken at 10% per annum. It is believed that this will be reasonable in the light of rising interest rates and local taxes.

Annual calculations are based on 330 operating days per year, 24 hours per day. This gives a total of 7,920 operating hours per year.

ALTERNATE SYSTEMS

In the tabulations which follow, several alternate control systems are included, for most processes. Aside from cost, other factors enter into the selection of a system. The nature of the process to some extent dictates or precludes the use of a particular type of control. For example, some collected dusts can be reused directly in the process or used as burden in the plant following agglomeration; the wet or dry state of the collected dust may afford a convenience to disposition of the dust according to the current practice of a particular plant.

The gas may be reusable as a process material in the plant, where changes in its temperature and humidity by the cooling system would have to be considered in the total plant energy economy. The local cost of treated water, space requirements for retreatment facilities, and possible difficulties in using water near the process vessel may affect the choice of wet or dry systems.

The particle size and concentration of the effluent determine whether high efficiency gas cleaning equipment (high-energy wet scrubber, electrostatic precipitator, or baghouse) is needed, based on particle size vs. efficiency experience data for different types of collectors. This data is largely in the form of proprietary design curves in the files of equipment manufacturers. For the purposes of this study, the dividing line between low-and high-energy wet scrubbers is 12 inches of water pressure drop across the collector, with high-energy applications generally using several times this pressure drop.

The nature of the dust collector equipment to be used largely determines the extent and method of cooling the process gas. The process effluent may vary in temperature from 100°F for material transfer point ventilation to 3000°F or higher for furnace exhaust. This gas may be quenched by air dilution or water sprays to a lower temperature, or undergo a heat exchange to cool without adding material to the effluent stream. If the gas is combustible, it may initially be burned, with an excess of air to insure completness of combustion, where a fire or explosion hazard would exist. A wet-type cleaner may treat water-quenched or hot gases directly. The electrostatic precipitator used on highly (electrically) resistive particles requires a degree of cooling and humidification control to be effective and of economical construction. On the other hand, over-cooling or over-quenching can result in condensation with resultant corrosion, collector surface fouling, and dust handling problems in dry precipitators, and baghouses as well. Thus, in general

- excess air is added to the effluent stream where combustion occurs, in a water-cooled or other heat-exchange vessel;
- water addition completes the cooling for a wet system;
- indirect cooling by heat exchange will provide the most economical cooling to about 500°F in dry systems;
- added humidification by water sprays usually completes the treatment of gases prior to electrostatic precipitation;
- air dilution for bag temperature control usually completes pre-baghouse cooling.

Finally, to achieve economical fan power levels, the gas volume is kept low by gas cooling especially with high-energy wet scrubbers. This ultimate effluent gas, if sulfur oxides persist in significant degree to this point in the system, must have sufficient lift in the form of thermal or mechanical energy, or stack height to disperse in the atmosphere.

SINTER PLANTS

The following tables contain capital and operating cost data for two sizes of sinter plants. Sinter plant control systems are usually designed so that one control unit handles gases coming from the windbox while a separate control unit receives dust collected at several points in the material handling system.

The attached estimate gives separate figures for the windbox and materials handling operation. Various combinations of types of collection equipment are used on sinter plants and it is therefore necessary to offer separate values for these two zones of collection. The total cost for a given sinter plant will be the sum of the cost for the windbox and the cost for the materials handling.

The tables do not include system components through recovery cyclones or windbox fans. Booster fans are included. Modifications only are included in the windbox stack item cost.

The capacity of the sintering machine for the tabulated gas volume and dust collection cost is based on the average nominal capacity, making normal sinter. Variations will occur with differences in the burden. For example, self-fluxing sinter capacity may be as much as 35 percent higher than a machine's normal capacity. (Symposium on Sinter Plants, Discussion, Iron and Steel Engineer, June, 1959.) In other reports no such change is noted. With self-fluxing sinter, more particulate matter passes through the cleaner.

The addition of oily turnings and borings to the burden generates oil mist in the windbox gas. One solution to this is the use of a very high energy wet scrubber system.

The temperature of the windbox gases is determined by the sintering process used on the machine. The gases are moist. Too low a temperature can result in corrosion -causing condensation and tacky dust handling problems in dry collectors.

SINTER PLANT (WINDBOX) - WET SCRUBBER (LOW ENERGY)

Gas Volume - ACFM @ 325°F		105,000	630,000
Plant Capacity - TPD		1,000	6,000
	CAPITAL COST		
1.	Material*	$193,000	$880,000
2.	Labor	100,000	440,000
3.	Central Engineering	72,000	245,000
4.	Client Engineering	18,000	61,000
	TOTAL	$383,000	$1,626,000
	OPERATING COST ($/Yr.)		
1.	Electric Power	$ 20,000	$110,000
2.	Maintenance	15,000	66,000
3.	Operating Labor	30,000	80,000
	Direct Operating Cost	$ 65,000	$256,000
4.	Depreciation	38,000	163,000
5.	Capital Charges	38,000	163,000
	TOTAL	$141,000	$582,000

* For items included in materials, see pages C-10 and C-17.

Note: 1) Prices: 1969 base.

SINTER PLANT (WINDBOX) - ELECTROSTATIC PRECIPITATOR

Gas Volume - ACFM @ 325°F	105,000	630,000
Plant Capacity - TPD	1,000	6,000
CAPITAL COST		
1. Material*	$180,000	$800,000
2. Labor	88,000	385,000
3. Central Engineering	72,000	225,000
4. Client Engineering	18,000	56,000
TOTAL	$358,000	$1,466,000
OPERATING COST ($/Yr.)		
1. Electric Power	$ 12,500	$ 77,000
2. Maintenance	14,500	59,000
3. Operating Labor	20,000	30,000
Direct Operating Cost	$ 47,000	$ 166,000
4. Depreciation	36,000	147,000
5. Capital Charges	36,000	147,000
TOTAL	$119,000	$ 460,000

* For items included in materials, see pages C-10 and C-17.

Note: 1) Prices: 1969 base.

SINTER PLANT (WINDBOX) - FABRIC FILTER

Gas Volume - ACFM @ 325^{0}F	105,000	630,000
Plant Capacity - TPD	1,000	6,000
CAPITAL COST		
1. Material*	$154,000	$800,000
2. Labor	72,000	340,000
3. Central Engineering	58,000	222,000
4. Client Engineering	14,000	55,000
TOTAL	$298,000	$1,417,000
OPERATING COST ($/Yr.)		
1. Electric Power	$ 8,500	$ 45,000
2. Maintenance	18,000	87,000
3. Operating Labor	20,000	30,000
Direct Operating Cost	46,500	162,000
4. Depreciation	30,000	142,000
5. Capital Charges	30,000	142,000
	$ 106,500	$ 446,000

* For items included in materials, see pages C-10 and C-17.

Note :1) This system is rarely used.

2) Prices: 1969 base.

SINTER PLANT (MATERIAL HANDLING) - WET SCRUBBER (LOW ENERGY)

Gas Volume - ACFM @ 135°F	48,000	250,000
Plant Capacity - Tons/Day	1,000	6,000
CAPITAL COST		
1. Material*	$194,000	$420,000
2. Labor	146,000	480,000
3. Central Engineering	81,000	184,000
4. Client Engineering	20,000	46,000
TOTAL	$441,000	$1,130,000
OPERATING COST ($/Yr.)		
1. Electric Power	$ 36,000	$ 95,000
2. Maintenance	17,600	45,500
3. Operating Labor	15,000	40,000
Direct Operating Cost	$ 68,600	$ 180,500
4. Depreciation	44,000	113,000
5. Capital Charges	44,000	113,000
TOTAL	$156,600	$ 406,500

* For items included in materials, see pages C-10 and C-17.

Note: 1) Prices: 1969 base.

SINTER PLANT (MATERIAL HANDLING)-ELECTROSTATIC PRECIPITATOR

Gas Volume - ACFM @ 135^{0}F	48,000	250,000
Plant Capacity - Tons/Day	1,000	6,000
CAPITAL COST		
1. Material*	$149,000	$420,000
2. Labor	91,000	195,000
3. Central Engineering	60,000	133,000
4. Client Engineering	15,000	33,000
TOTAL	$315,000	$781,000
OPERATING COST ($/Yr.)		
1. Electric Power	$ 7,000	$ 41,000
2. Maintenance	12,500	31,000
3. Operating Labor	15,000	20,000
Direct Operating Cost	$34,500	$92,000
4. Depreciation	31,500	78,000
5. Capital Charge	31,500	78,000
TOTAL	$97,500	$248,000

*For items included in materials, see pages C-10 and C-17.

Note: 1) Prices: 1969 base.

SINTER PLANT (MATERIAL HANDLING) - FABRIC FILTER

Gas Volume - ACFM @ 135^{0}F	48,000	250,000
Plant Capacity - Tons/Day	1,000	6,000
CAPITAL COST		
L. Material*	$120,000	$350,000
2. Labor	68,000	166,000
3. Central Engineering	49,500	116,000
4. Client Engineering	12,500	29,000
TOTAL	$250,000	$661,000
OPERATING COST ($/Yr.)		
1. Electric Power	$ 9,000	$ 38,000
2. Maintenance	12,800	36,500
3. Operating Labor	15,000	20,000
Direct Operating Cost	36,800	94,500
4. Depreciation	25,000	66,000
5. Capital Charges	25,000	66,000
TOTAL	$ 86,800	$ 226,500

*For items included in material, see pages C-10 and C-17.

Note: 1) Prices: 1969 base.

PELLETIZING PLANTS

The following tables contain cost data for a pelletizing plant of 1,500,000 tons per year. This is a commonly used plant capacity with larger output being achieved through use of parallel units. It is not likely that many pelletizing plants will be built whose capacity is less than that shown here. It is believed that the costs presented are reasonably typical of the several types of moving grate equipment now in use.

Like the sinter plant, several control systems are used at different points on the unit. The total cost is the sum of the cost at the dryer exhaust and the materials handling dust points.

Many pelletizing plants hold to the shaft furnace design, using multiples of the 60 ton/hr. furnace. A system of cyclones is included in this section for the cleaning of the process gas leaving the furnace. And also, air from the cooling unit and material handling points at the discharge station is cleaned separately.

PELLETIZING PLANT (MOVING GRATE - DRYER EXHAUST) - CYCLONE

Gas Volume - ACFM @ 250°F	320,000
Plant Capcity - Tons/Year	1,500,000

CAPITAL COST

1. Material*	$ 180,000
2. Labor	95,000
3. Central Engineering	69,000
4. Client Engineering	17,000
TOTAL	$ 361,000

OPERATING COST ($/Yr.)

1. Electric Power	$ 20,000
2. Maintenance	14,000
3. Operating Labor	30,000
Direct Operating Cost	$ 64,000
4. Depreciation	36,000
5. Capital Charges	36,000
TOTAL	$ 136,000

* For items included in materials, see pages C-10 and C-24.

Note: 1) Prices: 1969 base.

PELLETIZING PLANT (MOVING GRATE - MATERIAL HANDLING) - WET SCRUBBER (LOW ENERGY)

Gas Volume - ACFM @ 70°F	55,000
Plant Capacity - Tons/Year	1,500,000

CAPITAL COST

1. Material*	$ 80,000
2. Labor	54,000
3. Central Engineering	36,000
4. Client Engineering	9,000
TOTAL	$ 179,000

OPERATING COST ($/Yr.)

1. Electric Power	$ 22,000
2. Maintenance	7,000
3. Operating Labor	10,000
Direct Operating Cost	$ 39,000
4. Depreciation	18,000
5. Capital Charges	18,000
TOTAL	$ 75,000

* For items included in materials, see pages C-10 and C-24.

Note: 1) Prices: 1969 base.

PELLETIZING PLANT (SHAFT FURNACE - PROCESS EXHAUST)-CYCLONES

Gas Volume - ACFM @ 460°F	125,000
Plant Capacity - Tons/Hr.	60

CAPITAL COST

1.	Material*	$135,000
2.	Labor	82,000
3.	Central Engineering	55,500
4.	Client Engineering	13,500
	TOTAL	$286,000

OPERATING COST ($/YR.)

1.	Electric Power	$ 23,000
2.	Maintenance	11,300
3.	Operating Labor	15,000
	Direct Operating Cost	$ 49,300
4.	Depreciation	28,600
5.	Capital Charges	28,600
	TOTAL	$106,500

* For items included in materials, see pages C-10 and C-24.

Note: 1) Prices: 1969 base.

PELLETIZING PLANT (SHAFT FURNACE - MATERIAL HANDLING)

	CYCLONES	AND	WET SCRUBBER (LOW ENERGY)
Gas Volume - ACFM @ 70°F	30,000		19,000
Plant Capacity - Tons/Hr.		60	
CAPITAL COST			
1. Material*	$ 45,000		$35,000
2. Labor	32,000		22,000
3. Central Engineering	23,000		19,000
4. Client Engineering	6,000		5,000
	$106,000		$81,000
TOTAL		$187,000	
OPERATING COST ($/Yr.)			
1. Electric Power	$ 4,000		$ 7,500
2. Maintenance	4,000		3,500
3. Operating Labor	5,000		5,000
	$ 13,000		$16,000
Direct Operating Cost		$ 29,000	
4. Depreciation	10,500		8,000
5. Capital Charges	10,500		8,000
	$ 34,000		$32,000
		$ 66,000	

* For items included in material, see pages C-10 and C-24.

Note: 1) 15000ACFM capacity for once a week cleaning routine.

2) Prices: 1969 base.

COKE OVEN

Cost data are not presented for control of emissions from coke ovens. The engineering problems involved are still being investigated, both in the U.S.A. and abroad. Satisfactory control equipment, with proven industrial performance, has not yet been developed.

BLAST FURNACE

The attached table presents cost information for a typical modern large blast furnace. It is anticipated that most future blast furnaces in the United States will be of this size or greater. They will probably have the type of wet scrubbing system shown here. Older units with combinations of several types of control equipment are not likely to be copied in the future.

Blast furnace gas cleaning costs should be divided between emission control and normal plant operation. In the absence of an industry consensus, it is suggested that an equal share be allocated to each of these accounts. The portion of the top gas which is fine-cleaned for the blast furnace stoves is shown for a number of plants on pages C-31 to C-37 of the technical counterpart of this report, entitled, "Final Technological Report on a Systems Analysis Study of the Integrated Iron and Steel Industry," May 15, 1969.

BLAST FURNACE - WET SCRUBBER (TWO STAGE, HIGH ENERGY)

Wind Rate - SCFM	150,000
Gas Volume - SCFM	210,000

CAPITAL COST

1.	Material*	$1,427,000
2.	Labor	636,000
3.	Central Engineering	360,000
4.	Client Engineering	90,000
	TOTAL	$2,513,000

OPERATING COST ($/Yr.)

1.	Electric Power	$ 20,000
2.	Maintenance	100,000
3.	Operating Labor	40,000
	Direct Operating Cost	$ 160,000
4.	Depreciation	251,000
5.	Capital Charges	251,000
	TOTAL	$ 662,000

* For items included in materials, see pages C-10 and C-30.

Note:1)These are total costs of cleaning the furnace top gas of particulate matter. Since this operation serves the ends of both emission control and plant operational requirements (material recovery and fuel conditioning for re-use), a share of the cost should be apportioned to each account. It is suggested, in the absence of an industry consensus, that the shares be equal.

2)Prices: 1969 base.

BASIC OXYGEN FURNACE

The following pages contain cost data on several sizes of basic oxygen furnaces. They assume that a new plant is being designed and that the pollution control equipment is included in the original design. The figures cover a single furnace only. It is recognized that various combinations of multiple units are used in actual practice. The influence of this is discussed on page C-11.

Heat extracting hoods are included. These are total combustion systems for typical oxygen-blow rates, with excess air used for a portion of the cooling. Water additions for saturation in wet scrubber systems and for humidification (considerably less than for saturation) in electrostatic precipitator systems completes the cooling typically. For baghouse systems, the gas would be kept dry, using air dilution at the hood and before the baghouse with heat exchange means between.

BASIC OXYGEN FURNACE - WET SCRUBBER (HIGH ENERGY)

Gas Volume - ACFM @ 180°F	220,000	440,000	660,000
Furnace Size - Tons	100	200	300
CAPITAL COST			
1. Material*	$910,000	$1,460,000	$1,960,000
2. Labor	490,000	790,000	1,060,000
3. Central Engineering	250,000	390,000	470,000
4. Client Engineering	60,000	100,000	120,000
TOTAL	$1,710,000	$2,740,000	$3,610,000
OPERATING COST ($/Yr.)			
1. Electric Power	$ 207,000	$ 432,000	$ 664,000
2. Maintenance	68,000	110,000	145,000
3. Operating Labor	40,000	60,000	80,000
Direct Operating Cost	$ 315,000	602,000	889,000
4. Depreciation	171,000	274,000	361,000
5. Capital Charges	171,000	274,000	361,000
TOTAL	$ 657,000	$1,150,000	$1,611,000

* For items included in material, see pages C-10 and C-32.

Note: 1) One Furnace System. For effect on cost of combined cleaning systems on multiple furnace shops, see page C-11.

2) These estimates cover full combustion systems in which all of the gas leaving the converter is mixed with an excess quantity of air. All of the carbon monoxide is therefore burned to carbon dioxide. This is the common industry practice in this country. Systems have been designed which collect this gas in a substantially unburned state. Such non-combustion systems may offer certain economies. The exact extent of these economies has not yet been generally recognized in the industry.

3) Prices: 1969 base.

BASIC OXYGEN FURNACE - ELECTROSTATIC PRECIPITATOR

Gas Volume - ACFM @ 500°F	375,000	785,000	1,200,000
Furnace Size - Tons	100	200	300
CAPITAL COST			
1. Material*	$ 900,000	$1,600,000	$2,250,000
2. Labor	450,000	800,000	1,100,000
3. Central Engineering	250,000	410,000	550,000
4. Client Engineering	60,000	100,000	140,000
TOTAL	$1,660,000	$2,910,000	$4,040,000
OPERATING COST ($/Yr.)			
1. Electric Power	$ 90,000	$ 210,000	$ 310,000
2. Maintenance	66,000	116,000	162,000
3. Operating Labor	20,000	30,000	40,000
Direct Operating Cost	$ 176,000	$ 356,000	$ 512,000
4. Depreciation	166,000	291,000	404,000
5. Capital Charges	166,000	291,000	404,000
TOTAL	$ 508,000	$ 938,000	$1,320,000

* For items included in material, see pages C-10 and C-32.

Note: 1) One Furnace System. For effect on cost of combined cleaning systems on multiple furnace shops, see page C-11.

2) Prices: 1969 base.

BASIC OXYGEN FURNACE - FABRIC FILTER

Gas Volume - ACFM @ 275°F	238,000	600,000	892,000
Furnace Size - Tons	100	200	300
CAPITAL COST			
1. Material*	$ 660,000	$1,280,000	$1,840,000
2. Labor	360,000	690,000	990,000
3. Central Engineering	200,000	340,000	470,000
4. Client Engineering	50,000	90,000	120,000
TOTAL	$1,270,000	$2,400,000	$3,420,000
OPERATING COST ($/Yr.)			
1. Electric Power	$ 43,000	$ 89,000	$ 130,000
2. Maintenance	59,000	112,000	160,000
3. Operating Labor	20,000	30,000	40,000
Direct Operating Cost	$ 122,000	$ 231,000	$ 330,000
4. Depreciation	127,000	240,000	342,000
5. Capital Charges	127,000	240,000	342,000
TOTAL	$ 376,000	$ 711,000	$ 1,014,000

* For items included in material, see pages C-10 and C-32.

Note: 1) One Furnace System. For effect on cost of combined cleaning systems on multiple furnace shops, see page C-11.

2) This system is used in Europe, but so far has not had an American application.

3) Prices: 1969 base.

OPEN HEARTH FURNACE

The following tables contain cost data for open hearth furnaces. They are based upon the addition of gas cleaning equipment to an existing furnace shop. It is not likely that many new open hearths will be built in the future. The figures shown are for a single furnace. The effect upon cost of multiple furnace combinations are discussed on page C-11of this report.

It is assumed that waste heat boilers and boiler fans are existing at the furnaces, and needed stack modifications are included in the estimates, along with booster fans. Waste heat boilers, while they contribute to pollution control by cooling the gases (without adding additional material to the gas stream which would increase size and cost of subsequent equipment), also serve the plant energy economy, and have been in general use on open hearth furnaces having no abatement equipment. Thus, they are not included in the cost of air pollution control and no credit is assigned for steam produced.

The estimates are based on averaged data for current oxygen-blown furnaces of different sizes, charged typically with 50% hot metal, 50% cold scrap. The typical gas cleaning equipment begins with boiler exhaust gas at 500°F and 18% moisture.(Steam augmentation is assumed during the dry gas period after hot metal addition when fuel and atomizing steam rates are low, and during low-rate initial oxygen lancing when gas temperature is low and the checker water cooling sprays are not used.) Thus, temperature and humidity control are minimized for dry gas cleaning systems. This gas volume per ton furnace capacity diminishes on the average with increasing furnace capacity, and is cleaned directly in an electrostatic precipitator system. The gas is cooled by air dilution before a baghouse collector. The wet scrubber saturates the gas.

OPEN HEARTH FURNACE - WET SCRUBBER (HIGH ENERGY)

Gas Volume - ACFM @ 180°F	30,000	90,000	240,000
Furnace Size - Tons	60	200	600
CAPITAL COST			
1. Material*	$160,000	$430,000	$1,000,000
2. Labor	85,000	230,000	540,000
3. Central Engineering	60,000	140,000	280,000
4. Client Engineering	15,000	35,000	70,000
TOTAL	$320,000	$835,000	$1,890,000
OPERATING COST ($/Yr.)			
1. Electric Power	$ 24,000	$ 77,000	$ 210,000
2. Maintenance	13,000	33,000	76,000
3. Operating Labor	40,000	60,000	80,000
Direct Operating Cost	$ 77,000	$ 170,000	$ 366,000
4. Depreciation	32,000	83,500	189,000
5. Capital Charges	32,000	83,500	189,000
TOTAL	$ 141,000	$ 337,000	$ 744,000

* For items included in materials, see pages C-10 and C-36.

Note: 1) One Furnace System. For effect on cost of combined gas cleaning systems on multiple furnace shops, see page C-11.

2) A variance from this design and cost is noted for a tar-fired furnace with no waste heat boiler. Gas volume at higher temperatures before and after saturation, and other factors lead to a 60% higher cost.

3) For a discussion of unusual problems encountered when installing new collecting equipment at existing furnace shops, and an indication of cost variances, see page C-11.

4) Prices: 1969 base.

OPEN HEARTH FURNACE - ELECTROSTATIC PRECIPITATOR

Gas Volume - ACFM @ 500°F	29,000	85,000	225,000
Furnace Size - Tons	60	200	600
CAPITAL COST			
1. Material*	$130,000	$320,000	$700,000
2. Labor	70,000	170,000	380,000
3. Central Engineering	52,000	110,000	200,000
4. Client Engineering	13,000	30,000	50,000
TOTAL	$265,000	$630,000	$1,330,000
OPERATING COST ($/Yr.)			
1. Electric Power	$ 5,000	$ 15,000	$ 45,000
2. Maintenance	11,000	25,000	54,000
3. Operating Labor	20,000	30,000	40,000
Direct Operating Cost	$ 36,000	$ 70,000	$ 139,000
4. Depreciation	26,500	63,000	133,000
5. Capital Charges	26,500	63,000	133,000
TOTAL	$ 89,000	$196,000	$ 405,000

* For items included in material, see pages C-10 and C-36.

Note: 1) One Furnace System. For effect of combined gas cleaning systems on a multiple furnace shop, see page C-11.

2) For a discussion of unusual problems encountered when installing new collectors at existing furnace shops, and an indication of cost variances, see page C-11.

3) Prices: 1969 base.

OPEN HEARTH FURNACE - FABRIC FILTER

Gas Volume - ACFM @ 275°F	45,000	135,000	350,000
Furnace Size - Tons	60	200	600
CAPITAL COST			
1. Material*	$75,000	$210,000	$530,000
2. Labor	40,000	120,000	300,000
3. Central Engineering	36,000	80,000	180,000
4. Client Engineering	9,000	20,000	45,000
TOTAL	$160,000	$430,000	$1,055,000
OPERATING COST ($/Yr.)			
1. Electric Power	$ 8,000	$ 22,000	$ 54,000
2. Maintenance	7,700	21,000	51,000
3. Operating Labor	20,000	30,000	40,000
Direct Operating Cost	$ 35,700	$ 73,000	$ 145,000
4. Depreciation	16,000	43,000	105,500
5. Capital Charges	16,000	43,000	105,500
TOTAL	$ 67,700	$159,000	$ 356,000

* For items included in material, see pages C-10 and C-36.

Note: 1) One Furnace System. For effect on cost of combined gas cleaning systems on a multiple furnace shop, see page C-11.

2) This system is not currently in general use, but it has been successfully applied in the U.S.

3) For a discussion of unusual problems encountered in installing new collecting equipment at existing furnace shops, and an indication of cost variances, see page C-11.

4) Prices: 1969 base.

ELECTRIC ARC FURNACES

The following pages contain cost data relating to electric arc furnaces designed for production of carbon steel. The figures are for completely new installations. The special problems encountered when installing new control equipment in existing plants were discussed on page C-11. Each cost value applies to a system of two furnaces with a common gas cleaner capable of handling only one furnace at peak loads at any given time. For effect on cost of a different system of multiple furnace control see page C-11.

The volumes listed are based on typical oxygen blowing rates used in furnaces making carbon steel from cold scrap. Oxygen and exhaust rates may be considerably higher when making stainless heats. An excess of air would typically be added to the furnace gases for complete combustion of carbon monoxide and hydrocarbons (the latter, during the melt-down of oily scrap), and for cooling. These mixed gases would then be water quenched in wet scrubbing, and also in pre-conditioning of the particles before electrostatic precipitation, though less water would be used in the latter system to avoid condensation and to optimize the temperature and humidity conditions for effective precipitation. Although, for baghouse collection, these gases also could be water quenched to some extent, effecting an economy in collector size,it is more typical to cool by use of a radiating exchanger, and to finish the cooling with controlled air dilution just before the baghouse.

ELECTRIC ARC FURNACE - WET SCRUBBER (HIGH ENERGY)

Gas Volume - ACFM @ 180°F	36,000	137,000	210,000
Furnace Size - Tons (each)	25	150	250
CAPITAL COST			
1. Material*	$173,000	$511,000	$723,000
2. Labor	93,000	277,000	388,000
3. Central Engineering	67,000	162,000	215,000
4. Client Engineering	17,000	40,000	54,000
TOTAL	$350,000	$990,000	$1,380,000
OPERATING COST ($/Yr.)			
1. Electric Power	$ 40,000	$174,000	$265,000
2. Maintenance	14,000	40,000	55,000
3. Operating Labor	40,000	60,000	80,000
Direct Operating Cost	$ 94,000	$274,000	$400,000
4. Depreciation	35,000	99,000	138,000
5. Capital Charges	35,000	99,000	138,000
TOTAL	$164,000	$472,000	$676,000

* For items included in materials, see pages C-10 and C-40.

Note: 1) Two Furnace System, alternating peak loads. For effect on cost of different combinations of furnaces per cleaning system see page C-11.

2) See also the section on Special Problems Encountered When Installing New Control Equipment in Existing Plants, page C-11.

3) A variation from these costs is noted in a case of a single furnace cleaning system where, after correction for the savings in a 2-furnace system, the cost would be 40% higher than indicated here. Remote placement of the scrubber is one factor in this variation.

4) Prices: 1969 base.

ELECTRIC ARC FURNACE - ELECTROSTATIC PRECIPITATOR

Gas Volume - ACFM @ 500°F	48,000	185,000	280,000
Furnace Size - Tons (each)	25	150	250
	CAPITAL COST		
1. Material*	$159,000	$465,000	$652,000
2. Labor	85,000	251,000	352,000
3. Central Engineering	61,000	151,000	197,000
4. Client Engineering	15,000	38,000	49,000
TOTAL	$320,000	$905,000	$1,250,000
	OPERATING COST ($/Yr.)		
1. Electric Power	$ 8,000	$ 30,000	$ 60,000
2. Maintenance	13,000	36,000	50,000
3. Operating Labor	20,000	30,000	40,000
Direct Operating Cost	$ 41,000	$ 96,000	$ 150,000
4. Depreciation	32,000	90,500	125,000
5. Capital Charges	32,000	90,500	125,000
TOTAL	$105,000	$277,000	$ 400,000

* For items included in materials, see pages C-10 and C-40.

Note: 1) Two Furnace System, alternating peak loads. For effect on cost of different combinations of furnaces per cleaning system see page C-11.

2) See also section on Special Problems Encountered When Installing New Control Equipment in Existing Plants, page C-11.

3) Prices: 1969 base.

ELECTRIC ARC FURNACE - FABRIC FILTER

Gas Volume - ACFM @ 275°F	60,000	230,000	350,000
Furnace Size - Tons (each)	25	150	250
CAPITAL COST			
1. Material*	$120,000	$441,000	$654,000
2. Labor	60,000	209,000	321,000
3. Central Engineering	44,000	140,000	196,000
4. Client Engineering	11,000	35,000	49,000
TOTAL	$235,000	$825,000	$1,220,000
OPERATING COST ($/Yr.)			
1. Electric Power	$ 8,000	$ 40,000	$ 52,000
2. Maintenance	11,000	39,000	57,000
3. Operating Labor	20,000	30,000	40,000
Direct Operating Cost	$ 39,000	$109,000	$ 149,000
4. Depreciation	23,500	82,500	122,000
5. Capital Charges	23,500	82,500	122,000
TOTAL	$ 86,000	$274,000	$ 393,000

* For items included in materials, see pages C-10 and C-40.

Note: 1) Two Furnace System, alternating peak loads. For effect on cost of different furnace combinations per cleaning system see page C-11.

2) See also section on Special Problems Encountered When Installing New Control Equipment in Existing Plants, page C-11.

3) Prices: 1969 base.

ELECTRIC ARC FURNACE

Combination Direct Evacuation Control and Furnace Canopy-Type Area Ventilation System - Fabric Filter

Gas Volume - ACFM @ 140°F	125,000	750,000
Shop Size - 2 Furnaces @ Tons (each)	20	120
CAPITAL COST		
1. Material*	$240,000	$1,200,000
2. Labor	102,000	480,000
3. Central Engineering	96,000	353,000
4. Client Engineering	24,000	88,000
TOTAL	$462,000	$2,121,000
OPERATING COST ($/Yr.)		
1. Electric Power	$ 18,500	$ 100,000
2. Maintenance	21,000	98,000
3. Operating Labor	30,000	40,000
Direct Operating Cost	$ 69,500	$ 238,000
4. Depreciation	46,000	212,000
5. Capital Charges	46,000	212,000
TOTAL	$161,500	$ 662,000

* For items included in material see pages C-10 and C-40.

Note: 1) Two Furnace System, alternating peak loads. For effect on cost of different furnace combinations per cleaning system see page C-11.

2) See also the section on Special Problems Encountered When Installing New Control Equipment in Existing Plants, page C-11.

3) Prices: 1969 base.

SCARFING

The following table presents cost data on scarfing units. These units are of two different sizes. The smaller size is usually employed when the billets to be handled are never larger than about 50 inches. Larger billets will require the larger gas cleaning equipment. The material cost excludes the cost of the Smoke Tunnel. In wet cleaning systems on a scarfer, the water circuit is normally coupled to an existing slab mill water treatment system, so that slurry treatment is excluded in this case.

SCARFING - WET SCRUBBER (HIGH ENERGY)

Gas Volume - ACFM @ 100°F	50,000	100,000
CAPITAL COST		
1. Material*	$114,000	$176,000
2. Labor	66,000	96,000
3. Central Engineering	48,000	68,000
4. Client Engineering	12,000	17,000
TOTAL	$240,000	$357,000
OPERATING COST ($/Yr.)		
1. Electric Power	$ 38,000	$ 75,000
2. Maintenance	10,000	14,000
3. Operating Labor	5,000	7,000
Direct Operating Cost	$ 53,000	$ 96,000
4. Depreciation	24,000	36,000
5. Capital Charges	24,000	36,000
TOTAL	$101,000	$168,000

* For items included in materials, see pages C-10 and C-45.

Note: 1) Prices: 1969 base.

SCARFING - ELECTROSTATIC PRECIPITATOR

Gas Volume - ACFM @ 100°F	50,000	100,000
CAPITAL COST		
1. Material*	$135,000	$204,000
2. Labor	85,000	112,000
3. Central Engineering	57,000	76,000
4. Client Engineering	14,000	19,000
TOTAL	$291,000	$411,000
OPERATING COST ($/Yr.)		
1. Electric Power	$ 8,000	$ 18,000
2. Maintenance	12,000	16,000
3. Operating Labor	5,000	7,000
Direct Operating Cost	$ 25,000	$ 41,000
4. Depreciation	29,000	41,000
5. Capital Charges	29,000	41,000
TOTAL	$ 83,000	$123,000

* For items included in materials, see pages C-10 and C-45.

Note: 1) Prices: 1969 base.

HCL PICKLING LINE - WET WASHER

The following table presents cost data on a spray washing system for an HCL Pickling Line acid fume removal system. Most modern lines are now sized for 80 inch strip. Fiberglass material is used for all duct and stack work. Fume is scrubbed by successive spray and eliminator units. For optional acid brick lined tunnel (6 ft. sq.) to outside fume collectors, add $184 per foot of length to capital cost total, and $44 per foot of length to annual operating cost total.

HCL PICKLING LINE - WET WASHER

Gas Volume - ACFM @ 100°F	130,000
Line Capacity	80 inch at 1,000 FPM

CAPITAL COST

1.	Material*	$ 81,000
2.	Labor	30,000
3.	Central Engineering	23,000
4.	Client Engineering	6,000
	TOTAL	$140,000

OPERATING COST ($/Yr.)

1.	Electric Power	$ 10,000
2.	Maintenance	6,000
3.	Operating Labor	5,000
	Direct Operating Cost	$ 21,000
4.	Depreciation	14,000
5.	Capital Charges	14,000
	TOTAL	$ 49,000

* For items included in materials, see pages C-10 and C-48.

Note: 1) Prices: 1969 base.

COLD ROLLING MILL - MIST ELIMINATOR

The following table presents cost data for an eliminator system to remove the palm oil and water mist emission at roll stands of a typical, large, five stand tandem cold rolling mill. The suction of the system picks up mist from closure plate enclosed areas at each stand, carries it through a tunnel to two mist eliminators and fans. The ventilation air thus cleaned is discharged up a stack. The treatment of collected oil for reuse or disposal is not included.

COLD ROLLING MILL - OIL MIST ELIMINATION

Gas Volume - ACFM @ 110°F	200,000
Mill Size	80 inch, 5 stand tandem

CAPITAL COST

1. Material*	$ 85,000
2. Labor	62,000
3. Central Engineering	29,000
4. Client Engineering	7,000
TOTAL	$183,000

OPERATING COST ($/Yr.)

1. Electric Power	$ 18,000
2. Maintenance	7,000
3. Operating Labor	7,000
Direct Operating Cost	$ 32,000
4. Depreciation	18,000
5. Capital Charges	18,000
TOTAL	$ 68,000

* For items included in materials, see pages C-10 and C-50.

Note: 1) Prices: 1969 base.

POWER PLANT BOILERS

The following pages contain cost data on several sizes of in-plant boiler houses. They assume that smoke and fly ash control equipment is being installed on an existing coal-fired boiler. The figures cover a single boiler only. Various combinations of multiple boiler-collector units are used in actual practice, with savings in larger sizes dissipated in additonal duct, dampers and complicated setup. The stack is considered to be already existing. Multiple cyclones, when used for primary collecting, are included as they yield no process advantage to the boiler. Booster fans are included.

Mechanically fed coal-fired boilers may achieve acceptable fly ash control with multi-cyclones alone. However, large modern boiler houses in integrated steel plants would usually use pulverized coal firing for efficiency and quick regulation of firing rate as well as ease of combined or auxiliary firing with blast furnace or coke oven gas. Pulverized coal's higher percentage of fly ash with a finer size grading requires the use of high efficiency control equipment, of which the electrostatic precipitator is almost solely used (often in conjunction with a mechanical primary collector), as it is more economical than wet scrubbing. The exhaust gas usually contains a significant amount of sulfur dioxide, which promotes effective cleaning with a smaller precipitator than would be required without it. The hot, buoyant gases leaving the precipitator disperse more readily than if cooled by scrubbing or for baghouse cleaning.

Sulfur dioxide emission suppression, using limestone injection with baghouse collection or absorbtive solution scrubbing, currently undergoing tests for public utility application, may eventually displace electrostatic precipitation of fly ash. But the trend in steel plant boilers is toward relatively pollution-free fuels, particularly gas and oil. Combustion devices to prevent carbon monoxide emissions are considered 100% process beneficial, and not funded as pollution control equipment. The formation mechanism and control techniques for nitrogen oxides emissions are currently under study; a preventive method will likely be sought for their limitation. The development of acceptable soot build-up removal means remains a problem.

POWER PLANT BOILER

Mechanically Fed, Coal Fired Boiler-Multicyclone Collector

Volume, ACFM @ 600°F	32,000	96,000
Boiler Size, pounds steam/hr.	50,000	150,000
CAPITAL COST		
1. Material*	$20,000	$ 60,000
2. Labor	10,000	30,000
3. Central Engineering	10,000	24,000
4. Client Engineering	2,500	6,000
TOTAL	$42,500	$120,000
OPERATING COST ($/Yr.)		
1. Electric Power	$ 2,300	$ 7,000
2. Maintenance	1,700	5,000
3. Operating Labor	7,000	15,000
Direct Operating Cost	$11,000	$ 27,000
4. Depreciation	4,300	12,000
5. Capital Charges	4,300	12,000
TOTAL	$19,600	$ 51,000

* For items included in materials, see pages C-10 and C-52.

Note: 1) One Boiler System.

2) Prices: 1969 base.

POWER PLANT BOILER

Pulverized Coal Fired Boiler - Electrostatic Precipitator

Volume, ACFM @ 300°F	100,000	200,000
CAPITAL COST		
1. Material*	$260,000	$440,000
2. Labor	140,000	230,000
3. Central Engineering	100,000	170,000
4. Client Engineering	25,000	45,000
TOTAL	$525,000	$885,000
OPERATING COST ($/Yr.)		
1. Electric Power	$ 28,000	$ 55,000
2. Maintenance	21,000	36,000
3. Operating Labor	30,000	40,000
Direct Operating Cost	$ 79,000	$131,000
4. Depreciation	52,500	88,500
5. Capital Charges	52,500	88,500
TOTAL	$184,000	$308,000

* For items included in materials, see pages C-10 and C-52.

Note: 1) One Boiler, Two Precipitator System.

2) Prices: 1969 base.

SAMPLE CALCULATION - OPERATING COST ($/Yr.)

The sample illustrates the calculations performed in arriving at the operating cost for a fabric filter installation on a 150 ton Electric Arc Furnace. Electric power costs (@ 3/4¢ per kwh) is obtained by calculating the total horsepower of all motors (plus power to lights and instruments) and multiplying by a cost per horsepower factor. Power to a fan motor is calculated by applying an efficiency to the power required for reversible adiabatic compression. This latter quantity is called "Air H.P." Power to a water pump motor is similarly calculated, the reversible pumping power requirement being called "Water H.P."

1.	Electric Power (*)		
	Basis:	$50/HP/Yr 800 HP Motor	
		$50/HP/Yr x 800 HP =	$ 40,000/Yr
2.	Maintenance		
	Basis:	4% of Capital Cost	
		Capital Cost $825,000	
		0.04 x $825,000 =	$ 33,000/Yr 6,000/Yr**
3.	Depreciation		
	Basis:	10% of Capital Cost	
		Capital Cost $825,000	
		0.10 x $825,000 =	$ 82,500/Yr
4.	Capital Charges		
	Basis:	10% of Capital Cost	
		Capital Cost $825,000	
		0.10 x $825,000 =	$ 82,500/Yr
5.	Operating Labor		
	Basis:	3/4 Man/Shift or 18 Manhours/Day	
		$5.00/Manhour	
		18 MH/Day x $5.00/MH x 330 Opr.Day/Yr =	$ 30,000/Yr
		TOTAL	$274,000/Yr

* See following page for notes.

** The difference from the 4% standard maintenance cost with bag replacement cost figured as described on page C-15.

*1. Electric Power Cost @ $0.0075/KWH

Operating Days = 330 Days/Yr

1 HP = 0.746 KW

$$\$0.0075/\text{KWH} \times 330\ \text{Days/Yr} \times 24\ \text{Hr/Day} \times 0.746\ \text{KW/HP} \times \frac{1}{.89\ \text{Motor Eff.}} = \$50/\text{HP per Yr}$$

*2. Air HP = 0.0001575 PQ

P = Static Pressure, in. water

Q = Volume, CFM

$$\text{Motor HP} = \frac{\text{Air HP}}{\text{Eff.}}$$

Eff. = Efficiency - Range 60 to 70%

*3. $$\text{Water HP} = \frac{\text{GPM} \times \text{H}}{3{,}960}$$

GPM = Gallons per Minute

H = Head, in Ft.

$$\text{Motor HP} = \frac{\text{Water HP}}{\text{Eff.}}$$

Eff. = Efficiency - Range 75 to 85%

METHOD OF DETERMINING EXHAUST GAS VOLUMES IN SIZING COLLECTING SYSTEMS FOR PRICING

The following sample illustrates the method of calculating the capacity of the collector in each estimated system. In general, the exhaust gases are cooled in transit through the system, so that successive items of equipment in the system will have different volumetric capacities due to gas volume changes with temperature and with the material additions (dilution air or water vapor) added to effect cooling.

The starting point is to determine a typical process exhaust gas composition and volume rate per unit of process throughput (as SCFM/ingot ton). In some cases this is determined solely by the oxygen lancing rate which generates the maximum exhaust volume during a steelmaking heat. In the open hearth case, since fuel and air are customarily added to the furnace during lancing, and waste heat boilers are generally used for cooling the exhaust gases, typical volumes of gas at the boiler outlet condition were selected as a starting volume for the gas cleaning system.

In the blast furnace, scarfing, sinter plant windbox, pelletizing (dryer or process), and power plant cases typical modern practice was used as a basis for determining the process exhaust volume. In materials handling and mist pick-up cases, where in-drawn ventilation air entrains particles, mist and vapors to be controlled, typical modern systems were studied to determine ventilation rates for adequate emission containment and to ensure the inclusion of sufficient pick-up points to contain a plant's effluent according to the extent that current technology can meet current standards.

Sample of volume determination method:

1.) Peak oxygen rate to process = 1500 SCFM at 32°F

2.) Combustion with air of carbon monoxide produced.
Carbon monoxide (maximum) = 3000 SCFM

$$2CO + O_2 + \frac{79}{21} N_2 \quad = \quad 2CO_2 + \frac{79}{21} N_2$$

$$+ \text{ excess air} \qquad\qquad + \text{ Excess air}$$

Combustion products

CO_2 3000 SCFM

N_2 $\frac{1}{2} \times \frac{79}{21} \times 3000$ SCFM = 5640 SCFM

Excess air = 500% in a typical case

$= 5 \times \frac{100}{79} \times 5640$ SCFM = 35,700 SCFM

Total 44,300 SCFM
44,300 SCFM x 1.7 (=Factor for two furnaces with alternating peak loads.)
= 75,500 SCFM

3.) Cooling the gases

The combustion occurs in a water-cooled, double-wall duct where cooling occurs by radiation and convection of heat to the walls. The gases leaving this section will typically be at about 1200°F. The size of such indirect heat exchanger will be determined by combining heat transfer and heat balance equations in an iterative calculation, based on certain reasonable assumptions of water temperatures, gas velocity, and water circuit capacity. Optimizing the total cooling and gas cleaning system is an extensive design task, so that typical equipment for each system has been selected for this study's estimates.

The cooling by air or water additions to the gases at 1200°F involves a heat balance for calculating resultant volume.

$$\sum_m M_m H_m + M_w H_w = \sum_n M_n H_n$$

M = pound moles of each component.
H = enthalpy of each component at conditions.
m = each component of uncooled gas.
n = each component of cooled gas.
w = water at spray water temperature.

For a final temperature of 500°F, suitable for an electrostatic precipitator, about 20% moisture is required by this analysis.

$$75{,}500 \text{ SCFM} \div .8 = 94{,}500 \text{ SCFM}$$

$$94{,}500 \text{ SCFM} \times \frac{(500 + 460)°R}{492°R} = 185{,}000 \text{ ACFM @ } 500°F$$

CAPITAL COST BREAKDOWN

The following tables illustrate the relative importance of various components in total material costs.

This is a very rough breakdown, and variations occur due to capacity and type of system. However, the relative orders of magnitude are well maintained. Certain conclusions can be drawn from this tabulation concerning the sensitivity of the total to local conditions. Foundations and structure may change considerably without having a marked effect on the total. Very often, a local requirement which tends to increase structure will simultaneously reduce foundations. The figures used for these two components are based upon simple structures supporting the collector near grade, and a soil bearing value of 4,000 lbs. per square foot.

The stack and fan components are rather closely related to gas volume and collector type. They are therefore relatively well defined. Electrical, while an important component, is predicted with comparative certainty from horsepower.

The key cost element is the collector itself, and it is to this item that the estimator gives the greatest attention. Generally this will involve obtaining a price quotation from a reliable manufacturer, although the published literature also contains useful information.

The second category, labor et al, is estimated on the basis of anticipated labor costs for each of the components in Total Material. Typical rules for this calculation are:

(a) Collector: Labor is about 35% of Material

(b) Fan, motor and starter: Labor is about 15% of Material

(c) Stack: Labor is about 100% of Material

(d) Ductwork: Labor is about 100% of Material

(e) Steel: Labor is about 30% of Material

(f) Foundations: Labor is about 130% of Material

(g) Electrical: Labor is about 150% of Material

MATERIAL BREAKDOWN

Sinter Plant - Windbox Gas Cleaning

	Wet Scrubber	Electrostatic Precipitator	Fabric Filter
1. Foundations	4	3	4
2. Ductwork and Stack Modifications	2	5	4
3. Collector	30	68	71
4. Fan and Motor	7	7	10
5. Structural	2	3	3
6. Electrical	7	9	5
7. Water Treatment & Piping	46	1	1
8. Controls	2	4	2
Total	100%	100%	100%

Sinter Plant - Material Handling - Dust Collection

	Wet Scrubber	Electrostatic Precipitator	Fabric Filter
1. Foundations	4	3	4
2. Ductwork and Stack	12	18	21
3. Collector	28	47	46
4. Fan and Motor	7	5	7
5. Structural	4	7	10
6. Electrical	8	17	9
7. Water Treatment & Piping	35	1	1
8. Controls	2	2	2
Total	100%	100%	100%

MATERIAL BREAKDOWN

Pelletizing Plant (Moving Grate) - Dust Collection

		Cyclone	Wet Scrubber
1.	Foundations	5	2
2.	Ductwork and Stack	15	5
3.	Collector	45	40
4.	Fan and Motor	14	20
5.	Structural	7	5
6.	Electrical	11	8
7.	Water Treatment and Piping	1	18
8.	Control	2	2
	Total	100%	100%

Pelletizing Plant (Shaft Furnace)

		Process Exhaust	Material Handling	
		Cyclones	Cyclones	Wet Scrubber
1.	Foundation	2	4	2
2.	Ductwork and Stack	10	20	12
3.	Collector	41	34	39
4.	Fan and Motor	18	13	18
5.	Structural	11	12	7
6.	Electrical	12	13	8
7.	Water Treatment & Piping	2	1	12
8.	Controls	4	3	2
	Total	100%	100%	100%

MATERIAL BREAKDOWN

Blast Furnace

		Two Stage Venturi Scrubber System
1.	Foundations	3
2.	Ductwork and Stack	10
3.	Collector	46
4.	Fan and Motor	-
5.	Structural	7
6.	Electrical	6
7.	Water Treatment and Piping	25
8.	Control	3
	Total	100%

MATERIAL BREAKDOWN

Basic Oxygen Furnace

	Wet Scrubber (High Energy)	Electrostatic Precipitator	Fabric Filter
1. Foundations	4	3	2
2. Ductwork and Stack	30	36	37
3. Collector	10	31	32
4. Fan and Motor	9	5	6
5. Structural	6	6	5
6. Electrical	7	8	7
7. Water Treatment and Piping	31	7	7
8. Controls	3	4	4
Total	100%	100%	100%

Open Hearth Furnace

	Wet Scrubber (High Energy)	Electrostatic Precipitator	Fabric Filter
1. Foundations	3	2	2
2. Ductwork and Stack Modifications	21	25	25
3. Collector	15	40	42
4. Fan and Motor	6	2	4
5. Structural	9	9	9
6. Electrical	11	10	8
7. Water Treatment and Piping	33	9	7
8. Controls	2	3	3
Total	100%	100%	100%

MATERIAL BREAKDOWN

Electric Arc Furnace (Direct Extraction Fume System)

		Wet Scrubber (High Energy)	Electrostatic Precipitator	Fabric Filter
1.	Foundations	4	3	2
2.	Ductwork and Stack	22	31	35
3.	Collector	15	35	34
4.	Fan and Motor	9	6	7
5.	Structural	7	6	7
6.	Electrical	10	10	9
7.	Water Treatment and Piping	30	5	2
8.	Controls	3	4	4
	Total	100%	100%	100%

Electric Arc Furnace (Combination Direct Evacuation Control and Furnace Canopy- Type Area Ventilation System)

		Fabric Filter
1.	Foundations	3
2.	Ductwork and Stack	37
3.	Collector	27
4.	Fan and Motor	10
5.	Structural	10
6.	Electrical	7
7.	Water Treatment and Piping	1
8.	Controls	5
	Total	100%

MATERIAL BREAKDOWN

Scarfing

		Wet Scrubber (High Energy)	Electrostatic Precipitator
1.	Foundations	2	2
2.	Ductwork and Stack	12	20
3.	Collector	30	55
4.	Fan and Motor	24	7
5.	Structural	5	3
6.	Electrical	16	7
7.	Water Circuit	7	2
8.	Controls	4	4
	Total	100%	100%

Power Plant Boiler

		Cyclone	Electrostatic Precipitator
1.	Foundations	6	3
2.	Ductwork	13	33
3.	Collector	40	20
4.	Fan and Motor	19	2
5.	Structural	8	19
6.	Electrical	12	17
7.	Water Treatment and Piping	0	1
8.	Controls	2	5
	Total	100%	100%

GASEOUS POLLUTANTS

The present report does not present cost data on equipment for the control of gaseous pollutants. Methods for the chemical treatment of gases for the removal of sulfur and nitrogen oxides are still under development. Reliable plant cost data will not be available for some time.

Volatiles emitted during the processing of coke oven by-products can generally be controlled by careful operating control of leaks, drips, drains, and vents. Any waste gases from flare stacks will probably contain sulfur oxides, for which treatment methods are not commercially available.

AREA VENTILATION AND EMISSION CONTROL

While the technology for cleaning of effluent material contained in exhaust ducts from enclosed processes has reached a state of development where clearly defined practices and equipment can be specified, the means to clean areas where process materials enter or leave the process enclosure and to clean the ventilated air from shop structures and outside handling areas is only now developing. Until the sizing and alternate methods have been tested by sufficient application, and competitive pricing has evolved, a definitive estimate of the cost and performance of truly adequate control means is premature.

The ventilation air volumes may be many times the volume of the gases cleaned in ducted exhaust circuits from the process; and explosion hazards at times occur with the influx of air. An example estimated here at the current level of development is the electric arc furnace melt shop with a combination of direct evacuation control at the furnace and a canopy above the furnace. This system provides containment and control during all phases of the heat cycle when the furnace roof is in place, and, in addition, good control in preventing fume from escaping from the building during those operations when there is no local containment at the furnace, such as charging, teeming,and slagging. The added volume to the collector is 1 to 2.5 times greater than with furnace flue gas treatment alone, or 2 to 3.5 times greater for the total system. In a case where the canopies are installed higher, at the roof truss, with no direct furnace evacuation, the volume is 4 to 5 times greater than it would be if shell evacuation alone were to be used. The basic oxygen furnace fume system, sized for peak volumes during oxygen lancing, could be fitted with auxiliary hoods and dampers to accommodate the hot metal charging and teeming area at low level, utilizing this peak evacuation capacity for area ventilation during off-blow periods. The same external operations at the open hearth would require added exhaust capacity, used in turn on each furnace of the shop. Drafts in the shop seriously effect the "catch" of open hoods, especially high-lofted canopies as applied to arc furnaces.

Alternate means are being applied for exhausting and fume removal. These include various pickup devices:

1. Close fitting hoods (with relatively low volume required) applied to pickling tanks and roll stands for mist pickup.

2. Low auxiliary hoods and partial enclosures applied to pouring operations of hot iron or steel, or the crushing, screening, loading and discharging of dry materials (sinter, ore, coal, coke, fluxes and other chemicals).

3. Tunnels as applied to scarfing units and conveying lines.

4. High canopies with isolation dampers for selective ventilation of high concentration dust areas, and total building air-change systems are currently being evaluated at a few melt shops. Buildings to enclose extensive areas of material handling and open processing with many dust generation points or discharges that are difficult to control at the source, are used to some extent now (at crushing and screening stations, for example).

In principle, the enclosure of such an area with cleaning and possibly recycling of the ventilation air therefrom could effect a reduction in volume and system complexity compared to that for many high pickup canopies. In practice, however, while emissions to the atmosphere could be significantly reduced, hazards would in many cases accompany returning air from the collector discharge to the workspace, limiting application of this principle. The magnitude of the task suggests the need for less costly, more effective, close-to-source control means. The volume required for adequate entrainment of emissions varies greatly, becoming much larger and less effective when pickup devices are farther removed from the source.

And while concentrations of pollutant material can be measured at points, the open-air distribution of concentration cannot be adequately profiled. The concentration of an air borne material beyond the plant area is subject to the weather and fall-out variables. Therefore, research is needed to quantitatively evaluate an area atmosphere by means that could be used for design criteria by equipment manufacturers and would give correlated information in performance guarantee tests and the abatement inspector's spot check.

With enough application of engineering design, less expensive means of controlling presently uncontained volumes will evolve. Plant design can accomplish some grouping of high dust areas to reduce ventilation requirements. Process change and new equipment design will increasingly consider pollution problems as a factor. Building design, currently based on natural ventilation means, could undergo changes to reduce the extent and facilitate the means of ventilation. And with optimization of means, a more realistic cost level will in time evolve.

Some prior cost tables give estimates of costs for ventilating dust and mist areas and cleaning the captured air around several processes. The estimates represent the most adequate systems currently being applied or quoted for process ventilation needs to supplement ducted process gas exhausting and cleaning:

Sinter plant material handling,

Arc furnace canopy-type area ventilation,

Scarfing tunnel evacuation,

Pickling line mist removal,

Rolling mill mist pickup.

EFFECT OF EFFICIENCY SPECIFICATIONS GREATER THAN CURRENT LEGAL REQUIREMENTS

In many localities, current legal codes specify a permissible particulate emission at the stack of not more than 0.05 grains per dry standard cubic foot of gas (or equivalent) exhausted to the atmosphere. Some facilities have met this requirement or even exceeded it with even fine, sub-micron sized steelmaking dust, using high efficiency filters, scrubbers, and precipitators. Manufacturers have been able to guarantee this performance with their equipment in a variety of applications. Also it is noted that blast furnace gas has been cleaned as finely as 0.005 gr./DSCF when necessary for reuse of the gas in high energy burners and fine checkerwork of the blast stoves (although this is a coarser dust than from steelmaking).

This quantity "0.05" is not necessarily an ultimate measure of the effluent quality that can be obtained. It came into use in the early 1960's, on the basis that an open hearth furnace stack plume containing fume at such a concentration had an "acceptable" appearance in many steelmaking areas. The value "0.05" correlated approximately with the maximum efficiency of electrostatic precipitators normally offered by manufacturers at that time for collecting this fume. However, the rapid growth in the use of oxygen lancing of steelmaking furnaces had led to larger quantities of finer fume in their waste gases today.

A stack plume cleaned to this level is not an invisible plume. The very fine steelmaking fume escaping at the stack effects a much larger degree of scatter of transmitted light than the larger particles previously encountered[1], and thus may be visible even in low concentrations. And yet, visibility of an exhaust plume persists as a means of checking collector performance, since it is a very simple comparison of "equivalent opacity" of the plume against the Ringelmann Smoke Chart.

Local code limitations based on Ringelmann opacity judgments may find a concentration of 0.05 grains/DSCF of steelmaking fume unsatisfactory. Where local codes are based on a schedule of allowable fume emission weight per ton throughput of processed material, the permissible fume rate customarily decreases for larger production equipment, so that above 30 - 40 tons per hour, the 0.05 level of control will not often be adequate.

Thus, the widespread use of 0.05 grains/DSCF as a general limiting level for emissions led to its choice as a basis for calculating the size and cost of collectors for each process in the tabulations in the appendix. But, in recognition of the use of more restrictive enforcement methods in some steelmaking areas, and because of the trend in promulgating air quality criteria which may suppress the emission sources in an area to an increasing degree, the following indications are drawn of the difference in cost for fume collecting systems capable of an efficiency beyond the currently practiced or currently attainable level.

[1] E. R. Watkins & K. Darby, The Application of Electrostatic Precipitation to the Control of Fume in the Steel Industry, Fume Arrestment, Special Report 83, of the Proceedings of the Autumn General Meeting of the Iron and Steel Institute (Brit.) 1964, Wm. Lea and Co., Ltd., London, p. 24.

Performance Equations

The performance equations of gas cleaners, as currently understood and applied, in selecting the size and operating parameters for a particular cleaning application have this in common - they are of the form:

$$\eta = 1 - e^{-F(x)}$$

where η = collection efficiency

or $1-\eta$ = penetration, dust loss, or outlet concentration as a fraction of the inlet concentration to the gas cleaner. It corresponds to some figure like 0.05, for example:

$$1-\eta = \frac{0.05 \quad (\text{grains/DSCF})}{\text{inlet conc.(grains/DSCF)}}$$

$$\ln \quad (1-\eta) = -F(x)$$

F(x) is a function of the size and operating parameters of the collector.

For a bag filter, Stairmand[2] has indicated

$$\eta = 1-e^{-S} \circ \frac{D'}{D}, \quad \frac{D'}{D} = \text{function of } (\frac{Dg}{Vf}) \text{ as shown}^{2}$$

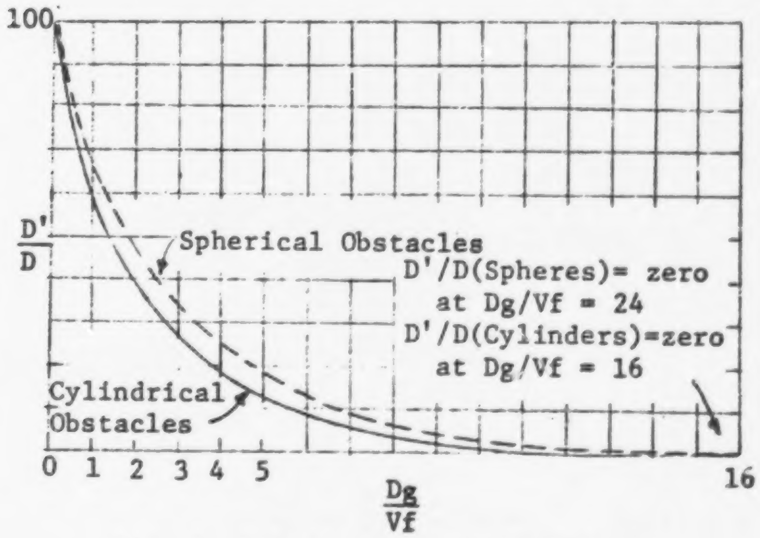


Fig. 1, Relation between Dg/Vf and target efficiency, D'/D where D = fiber diameter

---

[2] C. J. Stairmand, Dust Collection by Impingement and Diffusion, Trans. I. Chem. E., Vol. 28 (1950)

g = gravitational constant

V = velocity of gas at filter face

$= \frac{Q}{A} = \frac{\text{flow rate of gas}}{\text{area normal to flow}}$ = Filter Ratio

f = settling velocity of particle, as from Stoke's Law

$S_o = \frac{\text{total projected area of all fibers in the filter,}}{\text{cross section of filter bed}}$

both normal to the gas flow

For an electrostatic precipitator[3,4] the Deutsch equation is

$$\eta = 1-e^{-A'f'/Q}$$

where A' = collecting surface area

$f' = [1 + \frac{2(k-1)}{(k+2)}] \frac{rE^2}{6\pi\mu}$ = drift velocity

k = dielectric constant of particles

E = electric field strength

r = particle radius

μ = gas viscosity at temperature

And for wet scrubbers, Semrau's[5] correlation yields;

$$\eta = 1-e^{-\alpha(P_G + P_L)^{\gamma}} = 1-e^{-\alpha(P_T)^{\gamma}}$$

where P_G = contacting power of gas stream

$= 0.157\ F_S$

F_S = pressure loss across scrubber, in. water, exclusive of loss due only to velocity changes or friction losses across dry portions of the equipment.

P_L = contacting power of liquid stream

$= 0.583 p_F \frac{q_L}{Q}$

p_F = liquid feed pressure, psig.

q_L = liquid feed rate, g.p.m.

$P_T = P_G + P_L$ = HP/1000 CFM, based on Q

Q = actual gas flow at the scrubber, CFM

α, γ = constants for a particular dust, related to particle size and size distribution

Theoretical Performance Variables

To increase the efficiency of a collector, whose performance is describable by this logarithmic decay type function, it is necessary to increase F(X). The variable flow and equipment parameters comprising F(X) for a particular dust are respectively:

Bag Filter $S_\circ, \frac{D}{V}$ or $S_\circ, \frac{DA}{Q}$

Precipitator $\frac{A'E^2}{Q\mu} = \frac{2L\ W\ n\ E^2}{A\ V\ \mu} = \frac{2L\ W\ n\ E^2}{n\ b\ W\ V\ \mu} = \frac{2LE^2}{bV\mu}$

where W = collector surface span normal to flow

L = collector surface length in direction of flow

n = number of collecting ducts

b = separation of collecting surfaces

Scrubber F_S and $p_F(q_L/Q')$

where q_L/Q' is the liquid/gas ratio (gal/1000 CF)

a. Particle property effects:

1. Increasing f increases $\eta_{\text{bag filter}}$

   $f = \frac{4g\ r^2\ \rho}{18\mu}$

   where ρ is the density of particle.

   So larger, denser particles are collected more easily.

2. Increasing r increases $\eta_{\text{precipitator}}$. Again, larger particles are more easily attracted to the collector. Increasing the dielectric constant of the particulate, and decreasing resistivity by pre-conditioning via temperature and humidity (or SO_2 addition) increases η precipitator.

3. Increasing α or γ increases η_{scrubber}, as can be established[5]. Both increase with particle size.

---

[3] J. S. Lagarias, Predicting Performance of Electrostatic Precipitators, Journal APCA (1963) Vol. 13, No. 12

[4] M. Robinson, A Modified Deutsch Efficiency Equation for Electrostatic Precipitation, Atmospheric Environment, Permagon Press 1967, Vol. 1, pgs. 193 - 204.

[5] K. T. Semrau, Correlation of Dust Scrubber Efficiency, Jour. APCA, Vol. 10, No. 3, June 1960, pp. 200 - 207.

b. Dust collector geometry effects:

1. Increasing filter thickness or mat density, decreasing air/cloth ratio by using larger bag surfaces - increases $\eta_{\text{bag filter}}$.
2. Increasing precipitator length in the flow direction, or decreasing plate spacing or tube diameter (within limits of electrical stability) - increases $\eta_{\text{precipitator}}$. Since the dust loading decreases in the flow direction, it is possible to achieve an economy by successive stages of precipitation, each optimized electrically for maximum efficiency at the respective loading it will see, rather than simply extending the first stage field.
3. Decreasing the throat area of a scrubber increases its pressure drop and increases η_{scrubber}. This can be done by variable geometric arrangement or increasing water rate.

c. Utility parameter effects:

1. A partially blinded filter will be more efficient but at the cost of higher pressure drop and fan horsepower.
2. Increasing electric field strength increases $\eta_{\text{precipitator}}$ within the limits imposed by the geometry of the collector and dust properties with respect to sparking. This limit can be approached more closely with safety if automatic controls are used to regulate the discharge. Power use rises.
3. Venturi Scrubber. Increasing water usage or delivery pressure in a scrubber increases η_{scrubber}. Increased gas pressure drop gives improved efficiency at the cost of fan horsepower.

d. Flow effects:

1. Even though an increase in face velocity $(\frac{Q}{A})$ gives a higher theoretical efficiency in the inertial effect range, the effect is reversed in dealing with small particles ($<1\mu$). And for a filter with a fixed pressure drop and fixed cleaning routine, the dust buildup will dominate, so that if increased loading blinds the filter, causing spillage and less net cleaning, then the following holds. Decreasing the quantity of gas treated, or using a larger filter for lower face velocity increases $\eta_{\text{bag filter}}$.
2. Decreasing the amount of gas treated by lowering precipitator velocity and increasing residence time increases $\eta_{\text{precipitator}}$ if distribution of the gas is maintained uniform between the plates.
3. Increasing the quantity of gas treated or increasing throat velocity increases η_{scrubber}, by increasing pressure loss across the constriction, with an increase in P_G or fan horsepower.

e. Temperature effect on viscosity:

Increasing temperature increases μ gas.

1. Decreases $\eta_{\text{bag filter}}$

2. Decreases $\eta_{\text{precipitator}}$

   Increasing temperature increases the quantity of gas handled, again lowering these efficiencies.

   Besides altering flow and settling or drift velocity, temperature also endangers the bags, structures and mechanisms of the collectors. But filters and dry precipitators must have an inlet temperature above the water vapor (and sulfuric acid) dew point to avoid corrosion and dust caking on the collector, and causing dust handling problems in disposal conveyors.

3. Temperature effects the scrubber mainly in increasing the gas flow, and increasing the saturation water requirement.

Control System Cost Changes

It is a property of decay functions of the aforementioned type that at high efficiency, an increasingly large change in the exponent is required for a small increment in efficiency.

ELECTROSTATIC PRECIPITATION

For example, an electrostatic precipitator vendor[6] reports that the following increases in precipitator unit size are attendant to the respective efficiency changes:

Overall Efficiency[6] for a Particular Dust	Outlet Loading with 5.0 grains/DSCF Input Loading	Size of Precipitator Box and Unit Cost[6]
90%	0.5	X
99%	0.05	2X
99.9%	0.005	3X

This tabulation excludes ductwork, water sprays, hood with its cooling auxiliaries, stack; but includes the precipitator and its electrical components. The fan and motor size and cost, for a precipitator increase (1X), would be affected by an increment corresponding to an increased static pressure of about 1-1/2 inches of water (the loss through box X), with the volume remaining unchanged, for a precipitator increment, X

---

[6] private communication, Pangborn Corporation

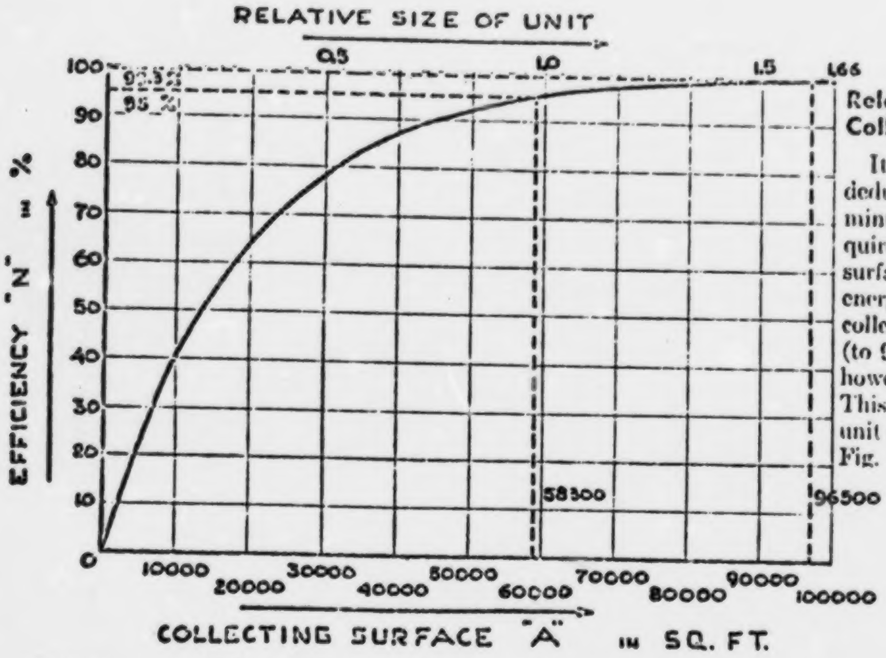
Horsepower increment = $\frac{S.P. + 1.5}{S.P.}$ x H.P.

Fan pressure increment = $\frac{S.P. + 1.5}{S.P.}$ x S.P.

for the total system fan.

Fan volume unchanged.

The following field data[7] are illustrative of this:



Relationship—Size and Collection Efficiency

It may be of interest to note that the dedusting of 315,000 cubic feet per minute of open hearth waste gases required 58,300 square feet of collecting surface for an efficiency of 95 %. By energizing the vacant sections, the collecting surface was increased 66 % (to 96,500 square feet). The efficiency, however, increased only 4.3 %, to 99.3. This relationship between size of the unit and collection efficiency is shown in Fig. 2

Fig.2 Relationship—precipitator size on collection efficiency.

---

[7] A. C. Elliott and A. J. LaFreniere, The Collection of Metallurgical Fumes from an Oxygen Lanced Open Hearth Furnace, Jour. APCA, Vol. 14, No. 10 (1964), p. 401.

The above variation in size corresponds to Deutsch's Law

$$(1-\eta) = e^{\frac{-A'f'}{Q}}$$

for a particulate of homogeneous size, shape, density, and composition.

$$\eta = \frac{\text{inlet loading } - R}{\text{inlet loading}} = 1-\frac{R}{\text{I.L.}}, \text{ where } R = \text{outlet loading.}$$

$$R = \text{constant}_1 \times e^{-\text{constant}_2 \times \text{length}}$$

$$\log R = \text{constant}_3 + \text{constant}_4 \times \underset{(\text{cost})}{\text{length}}$$

for a given process and precipitator.

However, real particulate varies in size, density, and susceptibility to charging (depending on surface and compositional variables) - so that the least collectable particles remain after each treatment, lowering the efficiency of subsequent treatments.[8] Case 2 below illustrates this with arbitrary efficiencies:

(Case 1), Deutsch's Law variation,

$$R:\quad 5\ \frac{\text{grains}}{\text{SCFD}} \rightarrow \substack{\text{Box}\\ X} \rightarrow .5 \rightarrow \substack{\text{Box}\\ X} \rightarrow .05 \rightarrow \substack{\text{Box}\\ X} \rightarrow .005$$

η:	90%	90%	90%
net η:	90%	99%	99.9%
net size:	X	2X	3X

(Case 2),

$$R:\quad 5 \rightarrow \substack{\text{Box}\\ X} \rightarrow .5 \rightarrow \substack{\text{Box}\\ X} \rightarrow .1 \rightarrow \substack{\text{Box}\\ X} \rightarrow .03 \rightarrow \substack{\text{Box}\\ X} \rightarrow .012 \rightarrow \substack{\text{Box}\\ X} \rightarrow .006 \rightarrow \substack{\text{Box}\\ 5/12X} \rightarrow .005$$

η:	90%	80%	70%	60%	50%	40%
net η:	90%	98%	99.4%	99.76%	99.88%	99.9%
net size:	X	2X	3X	4X	5X	5-5/12X

A body of blast furnace data [9] for a number of operating furnaces at various precipitator loadings yields the following progression, which shows this trend,

net η:	90%	95%	98%	99%	99.5%	99.9%	99.99%
net size:	.55X	.86X	1.4X	2X	2.65X	4.5X	7.5X

[8] G. Penney, Carnegie-Mellon University, Symposium on Gas-Solids Separation, January 14, 1969

[9] B. R. Berg, Development of a New, Horizontal-Flow, Plate-Type Precipitator for Blast Furnace Gas Cleaning, Iron & Steel Engineer Year Book, p. 786

Cost data from precipitator manufacturers indicate a close correspondence to Case 1 in variation of cost (= constant x length) with efficiency. Guarantees are made on efficiency rather than outlet loading because the precipitator is not adequately adjustable for cleaning a higher inlet dust concentration to the same outlet level (say 0.05). In fact, the higher loading may reach a point where spark-over occurs; so automatic electrical controls are used to maintain the highest collection efficiency just short of spark-over. (Large loading differences require design selection of plate spacing and voltage optimized for the loading and dust properties of the individual process effluent). The maximum guarantee is presently about 99.5%, although higher efficiencies (around 99.7%) can be reached.

The successive lowering of efficiency found with addition of identical precipitation units can be compensated; since each successive unit sees a lower dust loading, plates can be spaced more closely, and voltage optimized in each succeeding section, while avoiding spark-over. Still, each type of dust must be tested to determine its collectability as a function of precipitator length.

The following tables show some estimated cost differences from the system cost tabulations for 0.05 grains/DSCF for processes cleaned by electrostatic precipitation to various outlet dust concentrations. The variation is based on the Deutsch Law. Capital cost differences include:

Materials: precipitator plus a fraction of electrical.

Labor: corresponding to each of above at standard factors.

Engineering: scaled fraction materials plus labor.

Annual operating cost differences include 24% of capital cost difference (for capital charges, depreciation and maintenance), plus a fraction of the electric power for precipitator and fan horsepower increments. Only small variations were noted for capacity of the cleaner, so that only one size of cleaners are included for processes previously estimated at 0.05 grains per SCFD, in several sizes. This study gives cost differences for new equipment, not alteration costs.

EFFICIENCY (% DIFFERENCE AT)

SINTER PLANT - WINDBOX - ELECTROSTATIC PRECIPITATOR

Gas Volume - ACFM @ 325°F	630,000
Plant Capacity - TPD	6,000

Outlet Loading (R) for .8 $\frac{\text{grains}}{\text{SCFD}}$ input*	Capital Cost Difference (ΔK_R), $\%K_{.05}$
.125	-29
.05	0
.02	+29

Outlet Loading (R) for .8 $\frac{\text{grains}}{\text{SCFD}}$ input*	Annual Operating Cost Difference (ΔC_R), $\%C_{.05}$
.125	-23
.05	0
.02	+23

Outlet Loading (R) for .8 $\frac{\text{grains}}{\text{SCFD}}$ input*	Annual Direct Operating Cost Difference (ΔD_R), $\%D_{.05}$
.125	-17.5
.05	0
.02	+17.5

*4 $\frac{\text{grains}}{\text{SCFD}}$ effluent precleaned by 80% efficient recovery cyclones.

$$\frac{\log_{10}(\frac{R}{R_{.05}})}{\log_{10}(2.5)} = \frac{-\Delta K_R}{29\%} = \frac{-\Delta C_R}{23\%} = \frac{-\Delta D_R}{17.5\%}$$

EFFICIENCY (% DIFFERENCE AT)

SINTER PLANT - MATERIAL HANDLING - ELECTROSTATIC PRECIPITATOR

Gas Volume - ACFM @ 135°F	250,000
Plant Capacity - TPD	6,000

Outlet Loading (R) for 1 $\frac{\text{grain}}{\text{SCFD}}$ input	Capital Cost Difference (ΔK_R), $\%K_{.05}$
.125	-18
.05	0
.02	+18

	Annual Operating Cost Difference (ΔC_R), $\%C_{.05}$
.125	-15
.05	0
.02	+15

	Annual Direct Operating Cost Difference (ΔD_R), $\%D_{.05}$
.125	-10
.05	0
.02	+10

$$\frac{\log_{10}\left(\frac{R}{R_{.05}}\right)}{\log_{10}(2.5)} = \frac{-\Delta K_R}{18\%} = \frac{-\Delta C_R}{15\%} = \frac{-\Delta D_R}{10\%}$$

EFFICIENCY (% DIFFERENCE AT)

BASIC OXYGEN FURNACE - ELECTROSTATIC PRECIPITATOR

Gas Volume - ACFM @ 500°F	785,000
Furnace Size - Tons	200

Outlet Loading (R) for 4 $\frac{\text{grains}}{\text{SCFD}}$ input	Capital Cost Difference (ΔK_R), $\%K_{.05}$
.125	-9
.05	0
.02	+9
	Annual Operating Cost Difference (ΔC_R), $\%C_{.05}$
.125	-10
.05	0
.02	+10
	Annual Direct Operating Cost Difference (ΔD_R), $\%D_{.05}$
.125	-11
.05	0
.02	+11

$$\frac{\log_{10}\left(\frac{R}{R_{.05}}\right)}{\log_{10}(2.5)} = \frac{-\Delta K_R}{9\%} = \frac{-\Delta C_R}{10\%} = \frac{-\Delta D_R}{11\%}$$

EFFICIENCY (% DIFFERENCE AT)

OPEN HEARTH - ELECTROSTATIC PRECIPITATOR

Gas Volume - ACFM @ 500°F	85,000
Furnace Size - Tons	200

Outlet Loading (R) for 5 $\frac{\text{grains}}{\text{SCFD}}$ input	Capital Cost Difference (ΔK_R), $\%K_{.05}$
.125	-10
.05	0
.02	+10

	Annual Operating Cost Difference (ΔC_R), $\%C_{.05}$
.125	-9
.05	0
.02	+9

	Annual Direct Operating Cost Difference (ΔD_R), $\%D_{.05}$
.125	-7
.05	0
.02	+7

$$\frac{\log_{10}\left(\frac{R}{R_{.05}}\right)}{\log_{10}(2.5)} = \frac{-\Delta K_R}{10\%} = \frac{-\Delta C_R}{9\%} = \frac{-\Delta D_R}{7\%}$$

EFFICIENCY (% DIFFERENCE AT)

ELECTRIC ARC FURNACE - ELECTROSTATIC PRECIPITATOR

Gas Volume - ACFM @ 500°F [1]	185,000
Furnace Size - Tons [2]	150

Outlet Loading (R) for 3 $\frac{\text{grains}}{\text{SCFD}}$ input	Capital Cost Difference (ΔK_R), $\%K_{.05}$
.125	-10
.05	0
.02	+10

	Annual Operating Cost Difference (ΔC_R), $\%C_{.05}$
.125	-10
.05	0
.02	+10

	Annual Direct Operating Cost Difference (ΔD_R), $\%D_{.05}$
.125	-9
.05	0
.02	+9

$$\frac{\log_{10}\left(\frac{R}{R_{.05}}\right)}{\log_{10}(2.5)} = \frac{-\Delta K_R}{10\%} = \frac{-\Delta C_R}{10\%} = \frac{-\Delta D_R}{9\%}$$

Note: [1] Assumes humidification of process fume is capable of maintaining particle resistivity in satisfactory collection range.

[2] Two furnace system.

EFFICIENCY (% DIFFERENCE AT)

SCARFING - ELECTROSTATIC PRECIPITATOR

Gas Volume - ACFM @ 100°F 100,000

Outlet Loading (R) for 1 $\frac{\text{grain}}{\text{SCFD}}$ input	Capital Cost Difference (ΔK_R), $\%K_{.05}$
.125	-19
.05	0
.02	+19

	Annual Operating Cost Difference (ΔC_R), $\%C_{.05}$
.125	-18
.05	0
.02	+18

	Annual Direct Operating Cost Difference (ΔD_R), $\%D_{.05}$
.125	-17
.05	0
.02	+17

$$\frac{\log_{10}\left(\frac{R}{R_{.05}}\right)}{\log_{10}(2.5)} = \frac{-\Delta K_R}{19\%} = \frac{-\Delta C_R}{18\%} = \frac{-\Delta D_R}{17\%}$$

WET SCRUBBING

In the case of the venturi scrubber, a vendor[10] reports the following:

	Inlet Loading, Grains/DSCF				Outlet Loading[10] Grains/DSCF	Capital Cost[10]
	1.0	3.8	5.0	10		
Efficiency	90%	97.4%	98%	99%	.10	X
	96.2%	99%	99.24%	99.62%	.038	1.43X

The operating expenses vary similarly for a venturi scrubber as efficiency is increased. This is shown in Figure 3 and 4[11] for an open hearth application where a decrease in outlet loading from 0.1 to 0.01 grains/SCFD results in more than doubling the annual operating cost of the fan. For a given size adjustable venturi, the increased efficiency requires only an increase in available horsepower to the fan and selection of a higher pressure fan, and operating power consumption increases directly with the pressure drop.

PRESSURE DROP VS
SCRUBBER PERFORMANCE[11]

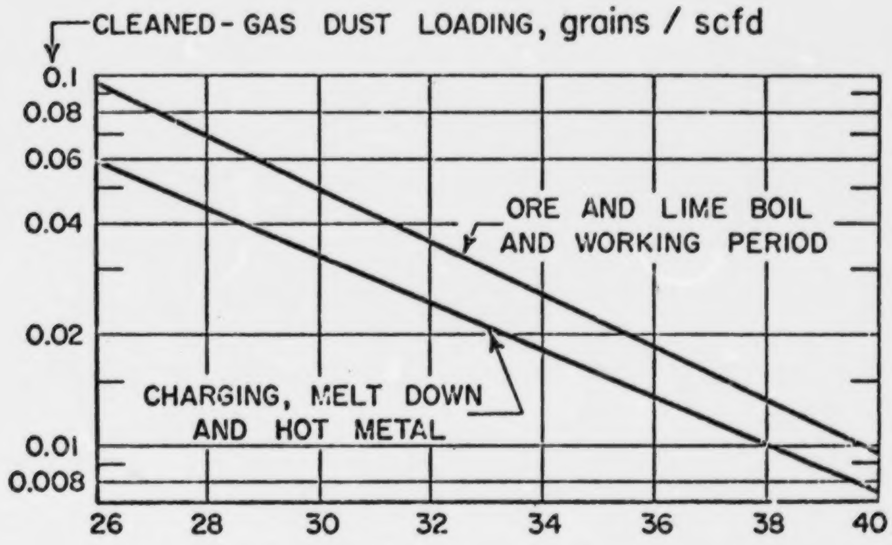


Fig. 3 PERMANENT PRESSURE DROP, inches of water

35 45 55 65 75

Fig. 4 FAN OPERATING COST, thousands of dollars/yr

[10] private communication, Pangborn Corporation

[11] Bishop, C. A., et al, "Successful Cleaning of Open-Hearth Exhaust Gas with a High-Energy Scrubber," Jour. APCA, 11 (2), 83-87, (February 1961)

The above venturi-cleaned open hearth application involves oxygen lancing during the periods noted on the upper curve. Dust loading was low (.82 to .87 grains/SCFD during oxygen periods, and .35 to .45 grains/SCFD during the charging, melting and hot metal addition periods). When this data is corrected to a typical peak 5 grains/SCFD loading for today's oxygen lanced furnaces it yields the following correlation:

R, outlet loading $(\frac{\text{grains}}{\text{SCFD}})$	ΔP, venturi pressure drop (in.w.)
.125	34.7
.05	41
.02	48.2

$$\frac{\Delta P_R}{\Delta P_{.05}} = \left(\frac{R}{.05}\right)^{-0.178}$$

However, Semrau[5] has applied his scrubber correlation to data from Basse[12] for the regression line of a plot of non-lanced open hearth gas cleaning efficiency vs. pressure drop at various operation conditions. This gives, for a peak 5 grains/SCFD inlet loading

R (grains/SCFD)	ΔP (in.w.)
.125	44
.05	78
.02	136

$$\frac{\Delta P_R}{\Delta P_{.05}} = \left(\frac{R}{.05}\right)^{-.62}$$

The higher numerical exponent seems more in line with results from other steelmaking fume.

Basse's[12] blast furnace data gives:

R, outlet loading $(\frac{\text{grains}}{\text{SCFD}})$	ΔP venturi pressure drop (in.w.)
.125	15.8
.05	23
.02	33.2

$$\frac{\Delta P_R}{\Delta P_{.05}} = \left(\frac{R}{.05}\right)^{-.403}$$

Basse's data for an electric furnace making 20% ferro-silicon show:

$$\frac{\Delta P_R}{\Delta P_{.05}} = \left(\frac{R}{.05}\right)^{-1.53}$$

For the typical scrap-charged electric arc furnace, wet scrubbing applications are sparse and data are not available for a scrubbing power-efficiency correlation.

Venturi gas cleaning data on the basic oxygen furnace have been developed[13]

R, outlet loading $(\frac{\text{grains}}{\text{SCFD}})$	ΔP, venturi pressure drop (in.w.)
.125	27
.05	41
.02	60

giving $$\frac{\Delta P_R}{\Delta P_{.05}} = \left(\frac{R}{.05}\right)^{-.417}$$

Data from a pilot size conventional venturi scrubber applied to clean scarfing machine effluent have been published[14]

R, outlet loading $(\frac{\text{grains}}{\text{SCFD}})$	ΔP, venturi pressure drop (in.w.)
.125	34
.05	60
.02	108

$$\frac{\Delta P_R}{\Delta P_{.05}} = \left(\frac{R}{.05}\right)^{-.631}$$

---

[12] B. Basse, Gases Cleaned by the Use of Scrubbers, Blast Furnace & Steel Plant, November, 1956, 44, p. 1307.

[13] H. P. Willet, D. E. Pike, The Venturi Scrubber for Cleaning Oxygen Steel Process Gases, Iron & Steel Engineer, 38, July 1961, p. 126.

[14] American Air Filter Co. bulletin 204-10M-3-65-CP

The following tables give some estimated cost differences for processes cleaned by wet scrubbers of the high energy types. The variation is based on the preceding scrubber application data. Capital cost differences include:

Materials:	Fan and motor plus fraction of electrical. The venturi itself is assumed adjustable and of sufficient strength for the higher pressure difference across its walls. Water rates are unchanged.
Labor:	Corresponding to each of above at standard factors.
Engineering:	Scaled fraction of materials plus labor.

Annual operating cost differences include 24% of (capital differences) plus electric power for horsepower increments.

EFFICIENCY (% DIFFERENCE AT)

BASIC OXYGEN FURNACE - WET SCRUBBER

Gas Volume - ACFM @ 180°F	440,000
Furnace Size - Tons	200

Outlet Loading (R) for 4 $\frac{\text{grains}}{\text{SCFD}}$ Input	Venturi Pressure Drop (ΔP, in.w.)	Capital Cost Difference (ΔK_R, $\%K_{.05}$)
.125	27.5	-4
.05	41	0
.02	60	+5.5
		Annual Operating Cost Difference (ΔC_R, $\%C_{.05}$)
.125	27.5	-6
.05	41	0
.02	60	+9
		Annual Direct Operating Cost Difference (ΔD_R, $\%D_{.05}$)
.125	27.5	-8
.05	41	0
.02	60	+12

An empirical relationship is indicated

$$\frac{\Delta K_R}{5.5\%} = \frac{\Delta C_R}{9\%} = \frac{\Delta D_R}{12\%} = \frac{\Delta P_R - \Delta P_{.05}}{60-41} = \frac{\Delta P_{.05}}{19}\left(\frac{\Delta P_R}{\Delta P_{.05}} - 1\right) = \frac{41}{19}\left[\left(\frac{R}{.05}\right)^{-.417} - 1\right]$$

$$\frac{\Delta K_R}{11.8\%} = \frac{\Delta C_R}{19.4\%} = \frac{\Delta D_R}{25.9\%} = \left(\frac{\Delta P_R}{\Delta P_{.05}} - 1\right) = \left[\left(\frac{R}{.05}\right)^{-.417} - 1\right]$$

Doubling the venturi pressure drop would cause a 25.9% increase in direct operating costs. Venturi loss of 41 in.w. is 85% of system loss, which accounts for 40% of total horsepower (including an unchanged water pumping and treatment system) in this case. Power cost is about 72% of direct operating costs. (40 x .85 x electric power fraction) + (11.8 x maintenance fraction) = 25.9%

Note: One furnace System

EFFICIENCY (% DIFFERENCE AT)

OPEN HEARTH - WET SCRUBBER

Gas Volume - ACFM @ 180°F	90,000
Furnace Size - Tons	200

Outlet Loading (R) for 5 $\frac{\text{grains}}{\text{SCFD}}$ Input	Venturi Pressure Drop (ΔP, in.w.)	Capital Cost Difference (ΔK_R, $\%K_{.05}$)
.20	32.6	-11
.10	50.2	- 6.5
.05	78	0
		Annual Operating Cost Difference (ΔC_R, $\%C_{.05}$)
.20	32.6	-15.5
.10	50.2	- 9
.05	78	0
		Annual Direct Operating Cost Difference (ΔD_R, $\%D_{.05}$)
.20	32.6	-19.5
.10	50.2	-12
.05	78	0

$$\frac{\Delta K_R}{-6.5\%} = \frac{\Delta C_R}{-9\%} = \frac{\Delta D_R}{-12\%} = \frac{\Delta P_R - \Delta P_{.05}}{50.2-78} = \frac{\Delta P_{.05}}{-27.8}\left(\frac{\Delta P_R}{\Delta P_{.05}} - 1\right) = \frac{78}{-27.8}\left[\left(\frac{R}{.05}\right)^{-.62} - 1\right]$$

$$\frac{\Delta K_R}{18.2\%} = \frac{\Delta C_R}{25.1\%} = \frac{\Delta D_R}{33.5\%} = \left(\frac{\Delta P_R}{\Delta P_{.05}} - 1\right) = \left[\left(\frac{R}{.05}\right)^{-.62} - 1\right]$$

Note: One Furnace System

EFFICIENCY (% DIFFERENCE AT)

SCARFING - WET SCRUBBER

Gas Volume - ACFM @ 100°F 100,000

Outlet Loading (R) for 1 $\frac{\text{grain}}{\text{SCFD}}$ input	Venturi Pressure Drop (ΔP, in.w.)	Capital Cost Difference (ΔK_R, $\%K_{.05}$)
.0833	44.3	-9
.05	61	0
.03	81.5	+11
		Annual Operating Cost Difference (ΔC_R, $\%C_{.05}$)
.0833	44.3	-17
.05	61	0
.03	81.5	+21
		Annual Direct Operating Cost Difference (ΔD_R, $\%D_{.05}$)
.0833	44.3	-23
.05	61	0
.03	81.5	+28

$$\frac{\Delta K_R}{11\%} = \frac{\Delta C_R}{21\%} = \frac{\Delta D_R}{28\%} = \frac{\Delta P_R - \Delta P_{.05}}{81.5-61} = \frac{\Delta P_{.05}}{20.5}\left(\frac{\Delta P_R}{\Delta P_{.05}} - 1\right) = \frac{61}{20.5}\left[\left(\frac{R}{.05}\right)^{-.631} - 1\right]$$

$$\frac{\Delta K_R}{32.6\%} = \frac{\Delta C_R}{62.5\%} = \frac{\Delta D_R}{83.4\%} = \left(\frac{\Delta P_R}{\Delta P_{.05}} - 1\right) = \left[\left(\frac{R}{.05}\right)^{-.631} - 1\right]$$

FABRIC FILTRATION

For an acceptable, constant dust penetration through a fabric filter, the face velocity or air volume to cloth area ratio must decrease with decreasing particle size and density or increased inlet loading. For a lower allowable penetration, the face velocity would similarly decrease. Thus, a more difficult or more thorough cleaning job would involve increased cost to provide more filter surface area. This is exemplified in the extreme case of a reverse jet-cleaned filter where face velocities are the highest encountered.

A reverse jet cleaned fabric filter calculated from the charts below[15] for 70% by weight of the dust loading less than 10 microns and S.G. above 2.0 yields the following information on sizing:

For Inlet Dust Loading Grains/DSCF	Efficiency Required for 0.05 Grains/DSCF Outlet	Filter Ratio Q/A (CFM/Sq.Ft.)	Filter Area
5	99 %	16.4	X
10	99.5 %	13.7	1.2X
20	99.75%	9.6	1.7X
25	99.8 %	7.6	2.1X

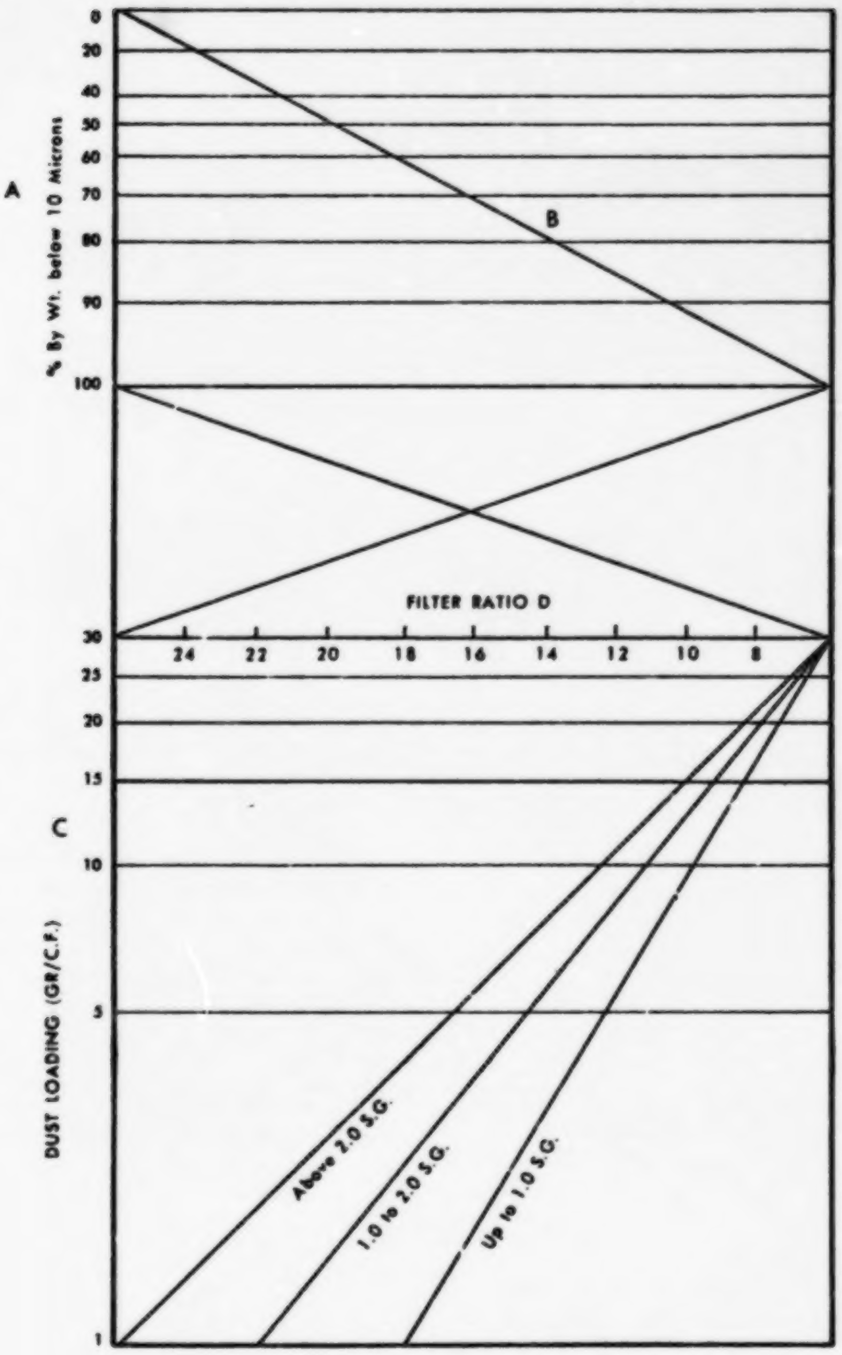
The effective filtering body is the dust cake layer on the bags. This does not at this time seem amenable to treatment which will improve efficiency. However, the bag, when new, and to a lesser extent when cleaned, holds little dust cake so that the fabric, with its small, dust laden fibers, is the basic filter until the filter cake layer reforms. As the small fibers break in service, the bag loses filtration capability. Additionally, the lower flow resistance of a cleaned bag passes a greater volume of air at reduced cleaning efficiency than when dust-coated; but at a higher velocity which betters the collectability of larger particles and worsens the diffusional efficiency dominating small particle collection.

An adequately designed baghouse will have a bag-cleaning cycle suited to the inlet dust loading from the process to which it is applied. This cycle is often automatically adjustable, so that the filter maintains the same average (time-wise) efficiency with variations in inlet dust loading and gas volume. The bag-cleaning period will begin when the collected dust causes the pressure drop through the filter to reach a set-point pressure.

In addition, the fabric weave and material is chosen with the special character of the process effluent in mind (such as particle size distribution). Economic factors (bag life and initial cost differences) also enter this choice, but increased efficiency can only be achieved by choosing from a group of fabrics which will give cleaning to the required level. Present practice usually gives efficiencies of 99%+, and bag filters frequently give the highest efficiencies of the applicable cleaning devices considered for a process; so this selective optimization does not offer much potential except as currently ongoing research reveals new materials and weaves.

---

[15] Buffalo Forge Company, Bulletin AP650



The following nomograph is presented as a convenient means of selecting Filter Ratio for preliminary determination of the size Aeroturn Dust Collector that will best satisfy the needs of your installation.

In many instances the nomograph will provide determination of the optimum Filter Ratio. Because of the great variety of possible service conditions and the effect of the characteristics of specific dusts, final determinations of Filter Ratio will be made by Buffalo Forge Company. This procedure provides the greatest assurance of correct and economic selection of equipment for your installation.

HOW TO USE

In order to select Filter Ratio, three conditions pertaining to your specific dust collection job are needed. They are:

a. The approximate percentage, by weight, of dust particles 10 microns or smaller.

b. Dust content of the air entering the Aeroturn Collector expressed in terms of grains (7000 per lb.) per cubic foot. Use average or normal values for both dust and air quantities.

c. Specific gravity of the material to be collected.

TO USE:

1. From appropriate point on vertical scale **A** draw horizontal line intersecting sloping line **B.**

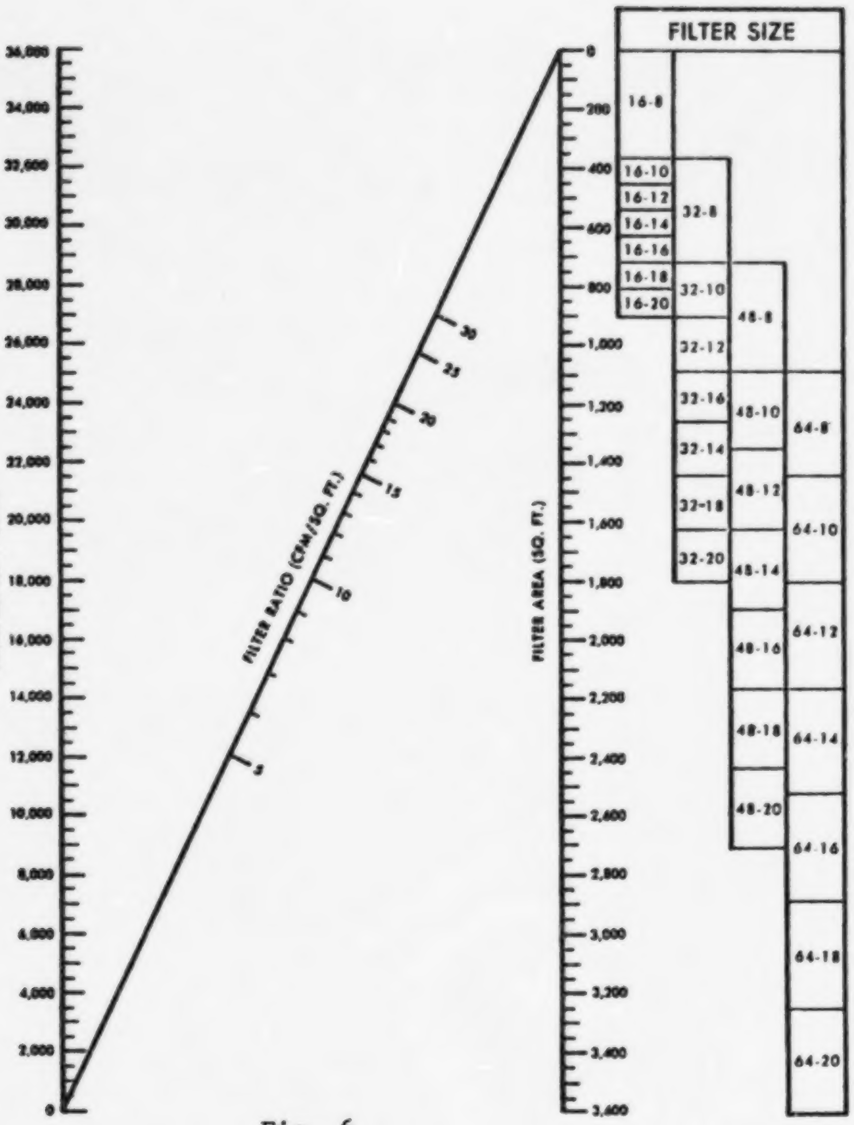
2. From appropriate point on vertical scale **C** draw horizontal line intersecting the sloping line which represents the proper specific gravity range for the material to be collected.

3. Now, draw a straight line between points selected in steps 1 and 2 above. The intersection of this line with horizontal scale **D** gives the Filter Ratio. This value may now be used in the Size Selection Chart, on the next page, to determine the Aeroturn Dust Collectors applicable to your requirement.

Fig. 5

As a case in point, a process having a generally large particulate may be adequately cleaned by a certain bag to .05 grains/SCFD. If lower outlet loading is required, a suitable bag, which gives similar results on a process with finer effluent, may be substituted. The overall cost may or may not be larger. The choices are presently limited by limited test results on filtration properties of fabrics, and state-of-the-art in fabric technology with regard to dust abrasion, flexural durability, and chemical and temperature resistance. Electrostatic interactions of various fabrics with dust particles may prove to be significant.

COLLECTOR SIZE [15]



HOW TO USE

This chart provides a convenient and accurate means for selecting the applicable size or sizes of Aeroturn Dust Collectors when Filter Ratio and required Air Cleaning Capacity are known.

1) Draw a line from the required Capacity through the applicable Filter Ratio to intersect the Filter Area scale.

2) From this point of intersection, draw a horizontal line through blocks designating Filter Size selections for desired Capacity.

3) If horizontal line passes through more than one Filter Size, first size intersected will be most economical. Subsequent selections will be less economical.

4) For capacities larger than shown: Use ½ the required capacity in the above procedure. Filter Size thus selected must be doubled for full capacity.

Fig. 6

No clear correlation has been advanced relating efficiency to operating parameters:

> A higher pressure drop may be expected to increase filtration action at the cost of additional power, but the trend of such variation is not known.
>
> A higher filter face velocity (higher air/cloth ratio) theoretically yields a higher efficiency of collection for particles large enough to be governed by inertial laws, but these are ordinarily cleaned to near 100% efficiency anyway, so the filter size is governed by loading. The small particles which escape collection migrate under diffusional impulses, and higher efficiency here would increase with residence time (lower face velocity, lower air/cloth ratio, thicker filter media). The relative effects of these coacting collection mechanisms is not sufficiently understood at present for use in practical design.

These foregoing factors are insufficiently defined to use at present for an economic study of the effect on costs of changed efficiency requirement.

CONCLUSIONS

A situation of diminishing returns is indicated by performance equations of the exponential type and in many cases a 0.05 grains/SCFD outlet concentration becomes a practical maximum level for improving efficiency, even though it is by no means an absolute limit.

The state of the art, then, allows the gas cleaner manufacturer to predict performance, design a collector, and guarantee it with some confidence to about 0.05 grains/SCFD outlet loading for particles greater than 2 microns in size. At lower outlet levels, his experience is limited. And the large change in size or operating parameters required for further small efficiency increases would magnify the uncertainties known to exist [16,17,4,18] in these simplified exponential relations and experience-based empirical constants used in them by the engineer.

Measurement techniques used to determine dust loading in the ducted stream before and after the collector leave much to be desired, especially where small concentrations and even smaller changes in concentration are to be used as evidence of guaranteed performance or violation. Lack of homogeneity of most dusts from iron and steel processes make the use of monitored data (light scattering or transmission, for example) difficult to interpret or the equipment difficult to calibrate, for all the variations in dust composition, size, gas flow rate, etc. caused by process changes during a heat cycle, or from heat to heat. Isokinetic sampling (sampling at stream velocity) with traversing probes involve much averaging (in time and space) with calculation and readjustment continuing during the traverse - this costly and of questionable accuracy. Null probes, too, operate with a significant degree of error in trying to balance small pressure differences. Neither approach to isokineticity can give a time history of emission rate during the course of a rapidly changing heat cycle as only two or three traverses can be run at best in an hour. Gas density (composition and state) and moisture content data should be monitored continuously and used as input to sampling rate determinations during the course of a sampling test; for deviations here can seriously effect the loading measured as grains of dust per dry standard cubic foot of carrier gas.

[16] Electrostatic Precipitation, Weakness in Theory, G. W. Penney, Mechanical Engineering, October 1968, p. 32.

[17] Turbulent Gas Flow and Electrostatic Precipitation, M. Robinson, Jour. APCA, April 1968.

[18] M. W. First, L. Silverman, Predicting the Performance of Cleanable Industrial Fabric Filters, Jour. APCA, Vol. 13, No. 12, Dec. 1963, p. 581.

From such quantitative data as can be obtained, control equipment is designed, often with a costly excess performance factor built-in, and guaranteed somewhat conservatively. The guarantee is proven (or indicated) by standard sampling tests, and no assurance is given that any particular level of Ringleman chart greyness will not be exceeded. Research is needed to find a method to inexpensively quantify dust concentrations; and agreement is needed to correlate design and enforcement bases of measurement.

Very fine particulate matter, because of greatly extended surface area, causes a much greater scattering of light, even in small concentration. A Ringleman comparison must thus in some way account for the nature of the emission being sampled to indicate relative concentration. If this correlation can be made, then this economical method of testing might be used to obtain both adequate design data and unquestioned legal evidence.

In the case of very fine steelmaking dusts from open hearth, electric arc, and basic oxygen furnaces, the collector performance is difficult to predict because,

a. The particle size distribution determination is difficult to quantify with present methods for sampled dust, and the correlation of this data to "in situ" dust in the furnace effluent gas is in doubt. (Large discrepancies in reported BOF dust sizing is a case in point). The smaller the size the greater the difficulty.

b. Agglomerative properties of the dust are not well established and the effect of this on sampled dust sizing and on collection mechanisms in the gas cleaners is not well understood.

c. The mechanism of collection upon which the performance equations are based (inertial and electrostatic forces) tend toward zero efficiency in the size range of the bulk of steelmaking dusts (<2 microns), where molecular interactions dominate the motion of particles.

Actually, any attractive interactions or agglomerative tendency would be beneficial to particle collection on a clean collecting element, but joining particles into larger, inter-adhesive masses would tend to blind a filter matrix (lessening gas handling capacity), or interrupt electrostatic precipitator field propagation about the wires and plates, and make the collector surface hard to clean off and the dust hard to handle. This in some cases necessitates close control of temperature and humidity.

For low velocity collectors (inherently large and thus economically inefficient for larger particle collection), a diffusional mechanism can give significantly large collecting efficiencies. (The effect is greatest, in theory, near zero microns size, and decreases with increasing particle size.) A middle ground exists around 0.9 microns in a bag filter where minimum efficiency can be as low as 10% - exactly in the center of concentration of some 70% of steelmaking dust. This is shown in an efficiency - particle size relation drawn by Stairmand[19] for a new, unused bag, for which the effect is most pronounced. See also figure 8, and for electrostatic precipitators, figure 11, where this effect seems to be indicated.

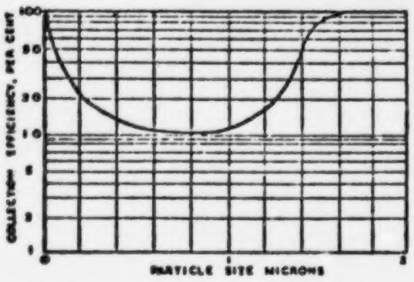


Fig. 7

New Fabric Filter[19]

Further research effort is indicated to:

a. Develop techniques for confident particle size distribution data representing the dust as it exists in the effluent gas.

b. Determine the extent of agglomerative effects and their agency in gas cleaning and effluent sampling mechanisms.

c. Utilize the diffusion mechanism for small particles in an optimum way while retaining economical and efficient inertial mechanisms for large particle collection. If the valley of low efficiency between the size ranges where diffusion and inertia are effective cannot be narrowed by this development, then another tack at development must investigate other gas-solid interaction phenomena for possible use in gas cleaning. Particle interaction effects may be important here.

d. Develop economical methods to measure dust concentrations - adequate for design purposes and well correlated to methods used for obtaining enforcement data.

In view of the foregoing difficulties it may be concluded that changes in legally required efficiency levels (to outlet loadings below about 0.05 grains/DSCF) would at this time be based on much questionable design measurement, and theory (whose extension into this range is also questionable). The cost of such changes, as indicated by present understanding of the mechanisms of collection with proven equipment, would become increasingly great for collection efficiency changes of very small magnitude-changes which can only be measured with an error of the same order as the change sought.

---

[19] C.J. Stairmand, Design and Performance of Modern Gas-Cleaning Equipment, Jour. Institute of Fuel (Brit.), Feb. 1956, p. 58.

FACTORS AFFECTING GAS CLEANER PERFORMANCE

The processes in the iron and steel industry can and do depart from design capacity and operating conditions for a number of reasons:

> Economic pressures dictate the continued improvement in productivity of an installed furnace.
>
> Technological improvements make possible significant increases in productivity (such as the introduction of oxygen blowing to open hearth and electric furnace steelmaking) of a new or existing facility.
>
> Batch handling of especially specified heats or runs of varying sizes and treatments.
>
> Slack market conditions may require output cutbacks.

And with changes in productivity effluent quantities increase or diminish both in gas volume and loading. Operating conditions in the gas cleaning system can vary with these conditions as well as with the weather, gas utilization program, raw material charge, etc. And non-continuous or batch type metallurgical processes vary during the course of a heat in both quantity and condition to the effluent.

To maintain satisfactory gas cleaning performance under these conditions it is necessary to have anticipated these factors in designing the pollution abatement system, rather than specifying for average conditions. Maximum capacity should be installed or adaptation to additional capacity provided. Adjustable equipment can often be used to optimize performance over a range of operations.

Provision should be made also in the initial installation to meet, or to add and adapt equipment to meet, expected future requirements of the pollution control codes both as to dust content of effluent and treatment of objectional gas and solid chemicals in the effluent.

Assuming proper design and selection of equipment, which would usually give superior performance over an extended life span with timely maintenance, and would offer the economies of optimization--any variation or variability in the process, control equipment or performance would generally require an added cost. And any unique feature of a particular gas cleaning application (particle size, dust loading, corrosion, etc.) would generally require a departure from a more general system design (and cost).

The following exerpt from G. Punch[20] summarizes the performance factors required for effective particulate removal:

---

[20] Gas Cleaning in the Iron & Steel Industry, Part II: Applications, G. Punch; Fume Arrestment, Special Report (83) of the proceedings of the Autumn General Meeting of the Iron & Steel Institute (Brit.), 26 November 1963. (1964), Williams Lea & Co., Ltd., London, p. 10.

Punch, Gas Cleaning

The Clean Air Act and the increasingly wide use of oxygen in both the classical and the recently developed top-blown converter processes have combined to create an urgent need for highly efficient cleaning of high-temperature effluent gases containing submicron iron oxide fume to the visibility threshold of 0.05 grains/CF. In order to satisfy this need, manufacturers of gas cleaning equipment had first to find how collectors which had already been well proved in other fields could be adapted to applications of which they had had no previous experience. This entailed not only the establishment of the empirical design parameters concerned with efficiency, but also a very close consideration of the ability of each type of collector to cope with unavoidable variations in gas volume, temperature, humidity, solids concentration, etc.

The flexibility of any given type of collector (i.e. its ability to operate efficiently without breakdown over a wide range of conditions) is much more important in practice than its theoretical efficiency at constant flowrate and temperature, etc., and the best unit for any given application will often not be the one which a comparison of efficiency and cost based on idealized operating conditions would indicate.

Every manufacturer who can offer a complete range of equipment must weigh very many factors before finally offering one particular type of collector. He may be handicapped, particularly in the case of a completely new installation, by a shortage of basic process data, but he can usually arrive at a fairly accurate assessment of the relative strengths and weaknesses of the possible units.

Although the size distribution and shape of dust or fume particles are of course the factors which determine the fundamental suitability or otherwise of any given design of collector for a particular application, other characteristics of the solids, the carrier gas, and the process itself must ... also be carefully considered and their effect on the collection device evaluated before a final selection is made.

The agglomerating propensities of the solid particles are important because they determine the size distribution of the particles presented to the collector. The extent to which agglomeration into clusters or chains of particles will have proceeded, and hence what the effective particle size will be immediately before the process of final collection is begun, cannot be accurately predicted, and in practice allowance is made for it in the empirical design constants used by equipment manufacturers. Agglomeration after collection affects the caking properties of dry material, making it more easily released from filter fabrics, less liable to re-entrainment during precipitator rapping, and more easily settled from liquid effluent.

The electrical resistivity of the material to be collected is of the utmost importance if a dry precipitator is to be used.

Punch, Gas Cleaning

> If the collected material is not free-flowing when dry it may create dust handling problems. Hygroscopic dust will give rise to similar difficulties in 'dry' collectors, unless humidity and the temperature of solids and gas can be maintained at safe levels by control of the process, lagging, external heating, warm air purging, or by a combination of these.
>
> For the collection of dusts which are corrosive when wet the obvious choice is a dry type of unit, unless there is a risk of condensation. If the waste gases contain water vapour which comes from the process itself, or has been added for cooling or conditioning them, and sudden temperature surges are likely, elaborate precautions against condensation may be needed, and a more compact wet unit constructed from corrosion-resistant materials may be more economical as well as more reliable.
>
> The physical and chemical characteristics of the carrier gas must also be carefully considered when a collector is being chosen. The effect of variations in gas temperature and humidity, in particular, must be carefully investigated especially if, as is almost always the case, they accompany or cause changes in gas volume and dust characteristics during and after collection. These factors are affected by the method of hooding, cooling, and volume and temperature control, but no matter how carefully these are engineered the characteristics of the process may still cause the collector to be subjected to conditions which are far from ideal and impair its operation either directly by affecting the collection process, or indirectly by hindering dust discharge or causing structural damage. Collectors of different types are more or less susceptible to different non-ideal conditions, as shown in Table I. The table is only intended to indicate some of the fundamental strengths and weaknesses of high-efficiency dedusters in relation to fluctuating operating conditions of one sort or another, and is not intended to be a comprehensive summary; it does, however, demonstrate the importance of factors which have nothing to do with the properties of particles.

Additionally, Table I from Punch[20] indicates operating conditions which affect the dust collector efficiency at a peak level of equipment maintenance and factors which require regular attention (cleaning the collector surface adequately to match dust loading, temperature control in dry collectors to minimize moisture and heat deterioration and maximize dust removal and handling properties) to insure peak efficiency throughout the life of the equipment.

The effect of operating conditions on the effective performance of the gas cleaning function, the effect of those conditions which cause maintenance difficulties and shorten service life, and the effect of those conditions peculiar to a particular furnace type or process on the design and selection of gas cleaning equipment--are best judged in the light of operating and design experience. The literature contains scattered discussions of this sort.

TABLE 1 Effect on collector performance of fluctuating operating conditions

	Dry plate precipitator	Fabric filter	Scrubber	Irrigated precipitator
Temperature	Normally up to 650°F with standard construction but momentary peaks of 1 000°F can be tolerated. Temperature must be selected to suit electrical characteristics of dust.	Normal maximum temperature depends on fibre used. Up to say 275°F with organic synthetics, 600°F with fibreglass. Higher peaks tolerable but reduce bag-life disproportionately.	Normally below 200°F with presaturation. Surges can be prevented if maximum water rate always used in saturator.	
Humidity	Insufficient moisture may lower efficiency by increasing dust resistivity. High humidity with low temperature may cause condensation, possible corrosion, insulator and plate cleaning and dust disposal difficulties. Accurate control of spray cooling essential.	Operation below dew-point leads to bag-cleaning troubles. Chemical and physical damage to fabric likely. Dust disposal difficulties.	Efficiency unaffected by changes in humidity, providing gas remains near saturation.	
Flowrate	Efficiency increased if flowrate reduced, although gas distribution may deteriorate.	Efficiency little affected by flowrate. Pressure drop reduced as volume falls.	Water-rate and/or throat area must be adjusted to compensate for changes in inlet volume. Alternatively volume may be kept constant by air-addition.	Efficiency increased by operation at lower flowrates.
Corrosive solids or gas	Corrosion can be avoided by accurate temperature control, insulation, auxiliary heating, bypassing, or corrosion-resistant materials of construction.	Filter fabric may be damaged.	Special materials of construction will prevent corrosion. High-pressure (high top speed) stainless steel fan impellers can give trouble.	Special materials of construction eliminate corrosion but price may rule out.
Inlet concentration	Initial design must be based on peak loading.	Efficiency not affected by increased loadings: effect on pressure drop depends on duration of surges, but can be reduced by temporary increase in cleaning intensity.	Initial design must be based on peak loading.	Initial design must be based on peak loading.

The following sections are discussions of emission cleaning for three iron and steel industry processes which present difficult problems of equipment selection, performance, and maintainability. These discussions were chosen for their concise and comprehensive consideration from an application point of view of the critical factors of equipment use. While they center on British practice (where raw materials, processes, codes, etc. have some variance from general American practice), the discussion of each factor remains pertinent, with perhaps some difference in degree, to a consideration of a corresponding American plant. So that, after considering all the conditions existing on a particular job of equipment application, an engineer may find somewhat more or less difficulty in his case.

SINTER PLANT[20]

MAIN STRAND GASES

The gases withdrawn from the main strand of a sinter machine present a fairly difficult gas cleaning problem, not, as in most other iron- and steelmaking applications, because high efficiencies must be achieved on very fine particles, but because of other characteristics of the dust and the gases themselves.

Volumes are great and the use of medium and high pressure drop collectors would involve large non-productive power consumption.

The waste gases contain large quantities of both sulphur oxides and water vapour. Consequently they have a high (acid) dewpoint so that condensation and corrosion are a constant danger, aggravated by the wide fluctuations of temperature which occur from time to time.

The coarser fractions of the dust burden are exceedingly abrasive.

Hence the ideal dust collector will have the following characteristics:

A pressure drop as low as possible.

Ability to operate efficiently over a wide range of temperatures without ill effect from occasional dampness of dust and collector internal surfaces.

A construction which minimizes condensation, lends itself to reasonably economical corrosion prevention, and is not susceptible to plugging during the occasional but inevitable periods of operation below dewpoint.

Freedom from abrasion troubles, preferably by complete avoidance of high velocities, otherwise by pre-collection of the coarse abrasive dust fractions prior to passing the gases through any collector in which high velocities are used.

Dust Characteristics

The particle size analysis of the dust content of sinter strand gases can vary between quite wide limits.... The type of dust to be dealt with depends on the mix fed to the strand,i.e. proportions of home and foreign ores and return fines, and also on whether or not the burden is conditioned in a pelletizing drum. It must be remembered that changes in dust composition occur as the rate of sintering alters and the relationship between temperature, flame-front penetration, and position on the strand varies.

Dust Loadings

The general level of dust concentration is affected greatly by the nature of the material fed to the machine and can vary from plant to plant between 0.1 and 1.0 grains/NCF and may occasionally reach 1.2 grains/NCF. The rate of solids emission is very sensitive to variations in the progress of the sintering process along the length of the strand. Dust is mainly generated early in the sintering process and again when the flame-front reaches the bottom of the bed. It has been suggested that in the intermediate zone the increased moistness of the lower part of the bed causes it to act as a crude filter and hence to pass less dust. It has been found that as complete sintering approaches the discharge end of the strand, i.e. as the mean hottest windbox number increases, the dust loading rises noticeably.

Gas Temperature

Gas temperatures usually fluctuate between 60°C and a maximum of 200°C but 100-150°C is the most common range....
(U.S. practice is in the range 300-400°F.)

Gas Composition

The only constituents of the waste gases which are important from the gas cleaning point of view are water vapour and sulphur oxides, both of which affect the frequency and severity of condensation in the cleaning system. There will usually be about 10% water vapour by volume in the gases and the sulphur oxide content, expressed as SO_2, may be as high as 1.5 grains/NCF. Unfortunately, no acid dewpoint figures are availiable, but water dewpoints as high as 50°C are encountered and acid dewpoints considerably higher than this must therefore occur. So far as condensation and corrosion are concerned, the relatively high proportions of water vapour and oxides of sulphur in the gases complicate the design and selection of gas cleaning equipment....
(But they tend to facilitate electrostatic precipitation.)

Choice of Dust Collector

In the authors' opinion the sulphur oxide content of the gases rules out wet methods of collection, since these would result in difficult liquid effluent problems, and saturated gases having hardly any thermal lift and still containing some sulphur oxides would constitute an air pollution problem worse in some respects than the original one.

The choice of a dry collector will be dictated by the quantity and size range of the dust in the case under consideration, the space available, the pressure drop which can be tolerated and the outlet loading required. Generally speaking, particularly for dusts at the coarser end of the normal range...and if an outlet concentration of 0.15 grains/NCF can be tolerated, a settling chamber will be adequate. If, say, 0.10 grains/NCF is the highest acceptable outlet loading, or the dust is finer, or a settling chamber cannot be accommodated within the space available, cyclones may be used, but their pressure drop (up to 6 inwg) is a disadvantage and they must be specially constructed to withstand erosion by abrasive dust particles. For a stack loading of less than 0.10 grains/NCF a more efficient type of collector must be used.

If outlet loadings down to 0.05 grains/NCF are required, the only suitable device is the electrostatic precipitator. Were it not for the constant danger of condensation, the fabric filter would be a possibility, but a filter fabric would 'blind' when operated under moist conditions. It is true that the silicone-treated fibreglass fabric (which would have to be used in any case to withstand the high maximum temperature) is much less susceptible to plugging than are the natural and organic synthetic cloths, and has been found to regain its porosity on drying out, but there would always be a risk of the cloth becoming 'starched' with soluble salts and failing prematurely through what can only be described as cracking. Fibreglass, which has poor flex resistance in the first place, is exceptionally vulnerable to this sort of trouble. This type of collector also compares unfavourably with the precipitator from the points of view of pressure drop, space requirement, and maintenance cost, and would not be recommended for main strand gas cleaning.

Although, in common with all other collectors, a precipitator for this application has to contend with occasional condensation, its operation is not unduly affected by moist conditions, providing precautions are taken against corrosion, and providing it has efficient rapping gear which will clear any...build-up and prevent progressive deterioration in its performance. The water vapour and sulphur oxides in the waste gases 'condition' the dust and together with the relative coarseness of the dust....
(...assist the precipitation process.)

The Head Wrightson sinter machine installed at the works of the Skinningrove Iron Co. Ltd, Saltburn-by-the-Sea, is provided with a Head Wrightson/Research Cottrell dry plate precipitator. The machine was designed to process a wide variety of home and foreign ore mixes, and experience indicated that the dust burden in the waste gases could be reduced by a simple settling chamber from 1.0 to 0.3 grains/NCF.* The gas volume from the 16 x 6ft square windbox machine is 180,000 CFM. The precipitator has two treatment zones, energized by a 15 kVA 230 mA transformer-rectifier set and operates at a treatment velocity of 6.8 ft/s. In view of the expected intermittent operation, it was thought advisable to fabricate the collector plates in copper-bearing 'Corten' steel (0.1%C max., 0.1 - 0.3%Si, 0.5 - 1.0%Mn, 0.3 - 0.5%Cu, 0.5 - 1.5%Cr, 0.1 - 0.2%P) and these have withstood the adverse conditions very well without noticeable deterioration. The interior of the precipitator shell is protected with gunned aluminous cement and the whole unit is thermally insulated to minimize condensation. The precipitator...was designed to operate at an average temperature of 300°F, and at an efficiency of 86.7%, corresponding to an outlet loading of 0.04 grains/CF. The design performance has been...achieved and, although the sinter plant has worked on a one or two shift per day basis and the precipitator has undergone an abnormal number of start-ups, there has been no deterioration of its internals. The sinter fan was inspected in August 1963, 20 months after commissioning, and showed no sign of wear other than a general smoothness over the faces of the blades; it is estimated that it will operate for at least another 3 - 4 years without requiring maintenance. The machine had produced 250,000 tons up to the time of the inspection. Reduced fan maintenance and plant downtime are two useful indirect benefits of efficient main strand gas cleaning.

The dust discharged from the precipitator hoppers is conditioned in a pelletizing drum and the pellets produced are returned to the process via the return fines conveyer.

*(This is lower than typical loading in American practice.)

DISCHARGE END EXHAUST SYSTEM

The whole of the discharge end of the sinter machine is usually completely enclosed; 100 tons or more of dust per day may be released by the equipment in this area (i.e. the end of the strand itself, the breaker, hot screen, and discharge to cooler). Air volumes vary with the size of sinter machine and the completeness of hooding, and are between 30,000 and 150,000CFM. Gas temperatures are usually between 40° and 150°C. Both the loading and the size range of the entrained dust are affected by the designs of hoods employed, and the exhaust volumes allocated to them, but dust burdens are typically in the range 4 -6 grains/NCF of which 80% might be <100 μm and 10% <10 μm.

Careful hood design, combined with adjustment of individual exhaust rates during commissioning, can reduce both grain loadings and the proportion of coarse abrasive particles carried in the gases. It is relatively easy to obtain collection efficiencies of 90-95% by means of simple high-efficiency cyclones, and the stack discharge in such cases will contain about 0.5 grains/NCF of dust, 90% of which is <10 μm. At this sort of grain loading the stack plume does not appear offensive; all the same it represents a very high rate of solids emission (up to 700lb/h on a large plant), and more and more interest is being shown in alternative higher-efficiency collection methods.

For cleaning the tip end emission the fabric filter and dry plate electrostatic precipitator are two obvious possibilities. Wet methods can be employed (self-induced spray units are fairly often used in the USA), but are not to be recommended because they introduce a secondary (liquid) effluent problem, and are liable to suffer from wet-dry interface troubles and sometimes from sludge discharge problems. At first sight, the fabric filter would appear to be ideally suited to this application, providing it is designed so as to avoid excessive scouring of the bags by abrasive dust, and properly maintained so that a small leak in one bag cannot 'grit-blast' a hole into an adjacent one and start a rapid and messy chain reaction. The first requirement is quite easily satisfied, but the second is not so straightforward and a short period of neglect could have expensive and inconvenient consequences in the form of extensive bag replacements and operation at reduced capacity. From the point of view of efficiency and capital cost, the fabric filter is a 'good buy', but running costs are a most important factor, and cannot be accurately forecast.

While the operating characteristics of the dry plate precipitator are quite predictable for this application, discharge end precipitation is difficult because of the high resistivity of the dust at the gas temperatures normally encountered, when the moisture content is less than about 1.5% by volume. In cold, dry weather the water vapour content may be as low as 0.5% by volume, and under these conditions unstable precipitator conditions are liable to occur at temperatures around 60°C.

The addition of relatively small quantities of water vapour, sufficient to raise the volume percentage to 2.0, leads to a marked

improvement in precipitator performance, as does the addition of 100 ppm of SO_2. If a guaranteed efficiency is to be maintained under every circumstance, and at all times, and if water vapour or SO_2 cannot be added, the precipitator will be perhaps three times as large as a unit which will operate satisfactorily under all but the driest conditions. It is therefore well worthwhile either to mix in gases from some other part of the sinter system or to add steam. If the problem of conditioning can be overcome this is a very straightforward precipitator application....
(Application of either dry system at the discharge end when water cooling of the sinter is employed could involve re-introduction of moisture control problems.)

QUENCH GASES

The quenching of hot fines in pug mill or drum gives rise to large quantities of fine dust, particularly during periods of erratic plant operation.

In a typical installation the volume of gas vented from the drum was 7600 NCFM at 40-120°C, containing between 5% and 24% water vapour by volume. It was found that the dust loading was greatly affected, not only by the quantity and distribution of spray water, but also by the quality of sinter being made. During normal operation of the machine the loading was found to vary between 1.3 grains/NCF when sintering was complete, and 4.7 grains/NCF when incompletely sintered material was being discharged from the strand. Shortly after commissioning, before the sprays had been adjusted and while the operation of the machine was abnormally erratic, the mean dust concentration had been 4.8 grains/NCF (corresponding to a rate of discharge of nearly 400 lb/h) and the peak loading 33.2 grains/NCF in gas volumes of 8500-11,000NCFM. This illustrates the effect of plant operation on stack emissions. The final emission rate averaged 140 lb/h compared to 280 lb/h from the main stack and 135 lb/h from the tip end cyclone stack.

The quench stack dust is rather fine (99% <100 μm, 30% <10 μm, 10% <3 μm). To date, to the best of the authors' knowledge, no attempt has been made to clean the gases, but if cleaning were required in an existing plant a self-induced spray washer or an orifice scrubber would be the best solution, unless the gases could be handled by an existing discharge end cleaning system. In a new plant the authors would recommend mixing the quench gases with the discharge end exhaust air to give a conditioned mixed gas stream capable of being cleaned in a precipitator of....
(conservative size to 0.05 grains/NCF.)
The problem can be entirely avoided if the hot returns are conveyed direct to the mixer (preheating the mix often has much to commend it).

THE OPEN-HEARTH FURNACE[20]

The open-hearth furnace emits waste gases equivalent to between 74,000 and 134,000 NCF/ton of crude steel. Volume rates of flow are usually within the range 170 - 280 NCFM/ton of furnace capacity. Fume loadings vary from one period of the melting cycle to another. During charging and melting down concentrations of less than 0.5 grains/CF are usual, and during fettling they are even lower. The highest fuming rates occur during refining and lancing, and loadings of 6 grains/NCF are common during oxygen injection. The concentration of fume is of course affected by the volume of excess air which is allowed to enter the furnace as well as by the fuming rate.

The composition of the furnace waste gases depends on the fuel used. The most important constituents from the gas cleaning point of view are water vapour and sulphur oxides. The percentage of water vapour may be as low as 2% or as high as 25% and a concentration of sulphur oxides calculated as SO_2 of 3.52 grains/CF has been reported for a producer gas fired furnace. A sulphur oxide concentration of 0.36 grains/CF has been reported for furnaces using 70% coke-oven gas and 30% pitch-creosote. In general high acid dewpoints are to be expected and if dry collection is to be used condensation must be guarded against.

Providing suitable precautions are taken against condensation, a dry collector may be used, and numerous dry plate precipitators have been installed in OH melting shops in recent years. Purely from the precipitation point of view, OH fume collection is fairly straightforward,
(with automatic controls)
due largely to the conditioning effect of the water vapour and sulphur oxides in the gases, but the fume tends to be 'sticky' and an efficient rapping system is essential. The collector casing must be well insulated to minimize condensation, and if the unit is to operate under pressure the top insulator housings must be pressurized with warm air to keep the insulators dry. Dust should preferably only be stored in the hoppers in an emergency because it tends to bridge, and it may be advisable to heat the hopper sides. Some condensation is bound to occur at start-up, and it is advisable to clear as much collected dust as possible from the interior of the precipitator while it is shut down. If this is not done conveyers and dust discharge valves may become clogged with moist dust. If possible the precipitator should only be energized when it has reached its normal operating temperature, so that little dust is collected in it when it is sweating. If these...precautions are observed the dry plate precipitator will operate continuously...if not, severe build-up, electrical and operating difficulties, and corrosion will be experienced.

A dry plate precipitator installation on a 250 ton tilting OH furnace......follows a waste heat boiler and ID fan, and is designed to clean 78,900 CFM of furnace gases at a maximum temperature of 280°C. The design inlet loading is 5 grains/NCF during oxygen lancing and the outlet cleanness 0.04 grains/NCF. The precipitator is insulated, the hoppers are steam-heated, and the insulator compartments on top of the unit are pressurized with 600 CFM of air at 200°F to prevent outward leakage of dirty gas and to keep the insulators both dry and clean. The precipitator has three treatment zones each of which is energized by a 21 kVA, 250 mA transformer rectifier set. This is quite a good example of a precipitator fitted into a very restricted site, utilizing turning vanes to reduce inlet and outlet duct sizes without detriment to gas distribution.

Punch, Gas Cleaning

The fabric filter may be used for OH gas cleaning but is more susceptible than the precipitator to condensation troubles, has a much higher power consumption, and requires more space. A filter serving one of the Ajax furnaces was reported to operate at a pressure drop of 8 inwg and to have a bag-life of only 20 weeks. There seems to be no reason why filters of modern design using improved high-temperature fabrics should not operate satisfactorily at a pressure drop of 4 -5 inwg with a bag-life of a year or more, but prolonged pilot-plant testing would be needed to prove the durability of the filter fabric.

Both the irrigated electrostatic precipitator and the high-energy scrubber are capable of cleaning OH fume to 0.05 grains/CF or better, but they would have to be constructed from espensive corrosion-resistant materials and would create secondary problems of liquid effluent treatment and loss of stack gas buoyancy.

ARC FURNACES[20]

Furnace Pressure Control

For consistently good fume control at minimum rates of extraction, automatic control of furnace pressure is essential. The indicated pressure which it is necessary to hold within the furnace depends on the position of the pressure pick-up. The accuracy of control required is of the order of ± 1.0 inwg for furnaces melting OH grades of steel but may be as fine as ± 0.03 inwg for a furnace producing alloy steels. The control system used must have a high speed of response if it is to cope with sudden fluctuations within the furnace.

Gas Cooling or Conditioning

Temperature at the outlet of the combustion chamber may be upwards of 1000°C and the gases must be cooled before they can be cleaned. The methods available are air dilution, indirect cooling by heat exchanger, and evaporative cooling. It is considered that the latter is often the best compromise on the grounds of simplicity, final gas volume, space requirements, and initial cost.

However, the type of collection device used will often dictate the manner in which cooling is carried out. With wet methods of collection, a comparatively small spray tower may be used (without fine control of the cooling sprays) and air dilution or indirect cooling would be pointless. If dry precipitation is preferred, the gases must be conditioned (most simply with water) and if a spray conditioning tower is required for this reason the gas will be spray cooled to the desired precipitator operating temperature. The fabric filter does not require pre-humidification of the gases for efficient operation and, is, moreover, exceptionally vulnerable to condensation. The preferred method of cooling in this case will depend upon whether the filter fabric is organic-synthetic (e.g. Orlon or Terylene) and therefore not suitable for operation at over 130°C, or fibreglass, which will withstand up to 250°C. In the former case air dilution or indirect cooling may be used, but in the latter spray cooling should present not difficulties providing a good control system is fitted.

System Capacity and Safety

....The details of safety require that...very conservative assumptions are made. The problem of explosion hazards has been considered in recent papers.

Air may enter the system at the air break between elbow and fixed fume pipe and at the combustion chamber, as well as through the furnace openings. The volume of air entering by each of these routes is unimportant providing (a) that control of fume is obtained and (b) that the final waste gas volume is such that even if combustion has been incomplete an explosive mixture cannot be formed.

The combined effects of combustion and dilution have been calculated for the lancing period, and are shown in Table II. However, the rate of evolution of combustion following the addition of oily scrap cannot be predicted, and it must be remembered that in practice the operation of a fume cleaning system must take second place to the production of steel; allowance must also be made for occasional deficiencies in the standard of both operation and maintenance of cleaning systems. Hence, although under ideal conditions an O_2 to waste gas ratio of 10:1 would no doubt be adequate, it is recommended that a ratio of not less than 15:1 be used.

Current understanding of the explosion problem is incomplete: explosions have been reported even in conservatively designed systems following errors in operation, and it is considered more prudent to use theory to predict the magnitude of apparent safety margins rather than to reduce these to the point where (due to the intrusion of incalculable factors) they do not exist, and a variation in the process or a mistake by an operator can cause an explosion.

TABLE II Effects of combustion and dilution

Ratio of waste gas oxygen injection flowrate	% Carbon monoxide if no combustion occurs	Approx. % combustion for safe operation (based on 100% oxygen utilization)
22:1	9·1	Nil
16:1	12·5	Nil
15:1	13·3	5%
14:1	14·3	10%
10:1	20·0	32%
6:1	33·3	50%
5:1	40·0	55%

GAS CLEANING

The furnace gases may be cleaned to 0.05 grains/CF by precipitator (wet or dry), fabric filter, high-energy scrubber, or combination scrubber-precipitator.

Punch, Gas Cleaning

> Dry plate precipitation is relatively straightforward providing the gases are properly conditioned. It is therefore ideally suited to direct extraction systems but much less so for hood or conventional hood vent installations. (A) 75 ton furnace...has been fitted with direct extraction fume control equipment and fume is to be collected by a dry-plate electrostatic precipitator (... unit referred to below). The lancing rate of this furnace is 1200 CFM and the volume during lancing, after combustion and cooling 49,200 CFM. The precipitator is designed to clean a total of 83,200 CFM from the existing furnace and another which is to be added in the future, from 6.5 to 0.05 grains/NCF.
>
> Furnace gases will pass through a water-cooled elbow and refractory-lined fixed duct connected by a power-operated movable sliding sleeve, into a gas burner followed by a combustion chamber. They will be cooled and conditioned in the rectangular spray tower and will enter the precipitator at a temperature of 500°F.
>
> The fabric filter is theoretically ideal, having a uniformly high efficiency irrespective of throughput but it must be carefully designed and protected against condensation. Filtering velocities may also be as low as 2 ft/min so that space limitations will often exclude this type of cleaner.
>
> The high-energy scrubber operating at a pressure drop of 30 inwg or more will do a satisfactory fume-cleaning job
> (U.S. codes would require about 45 inwg)
> and its compactness is a great advantage, particularly when the available space is limited. Power may be saved by regulating the fan in an efficient manner to suit the rate of exhaust required for fume control and the pressure drop needed at different periods of the melt to give the statutory final gas cleanliness, but this is only practicable if the pressure drop of the scrubber can be adjusted to the desired level over a wide range of flowrates.

It must be stressed, that in the long run, regular maintenance and attention to operating conditions affect the cost and effectiveness of any gas cleaning unit. The incorporation of automatic controls, operator-proof operating controls, scheduled preventive maintenance, anticipation of adverse process conditions and raw material possibilities are important to the continued performance of gas cleaning equipment after the guarantee period.

We will concern ourselves more specifically with the following parameters which affect gas cleaner performance:

1. Effect of gas volume changes on collection efficiency of a dust collector.
2. Effect of pressure drop within the gas cleaner on efficiency and capacity of collector.
3. Effect of dust loading: effect of collector surface renewal on pressure drop, volume and collecting efficiency.

4. Effect of particulate as generated in each matallurgical process (particle density, particle size, size distribution) on efficiency of each applicable dust removal device.

5. Effect of temperature on efficiency of and gas volume to collector, and required gas conditioning for cooling and humidification before dust removal.

   a. Gas analysis as it affects conditioning required prior to cleaning and exhausting. (Refer back to Punch's examples with respect to combustibles, SO_2, water vapor.)

   b. Corrosion and the use of water.

   c. Abrasion and chemical effects of dust.

6. Adaptability of the particulate removal system to removal of gaseous pollutants.

1. Effect of gas volume changes on dust removal efficiency---

As previously indicated, the volume of effluent gas emitted by a metallurgical process may vary greatly during a heat, or according to changing production level of the process. And since the efficiency of dust removal changes when volume changes, it becomes necessary to

---operate at constant volume with air substituted for effluent gas deficiency,

---or, use a gas cleaning device which adjusts itself to volume changes, or is adjustable to satisfactory efficiency over a range of volume.

Self-induced or orifice washers (of the Rotoclone type) and certain fluidized bed scrubbers can adjust themselves, essentially at constant efficiency. Adjustable throat venturis, orifice-wedge and flooded disk scrubbers can be adjusted to suit a range of gas flow. These and other wet scrubbers can also be uneconomically flooded to achieve the same effect.

Multiple units (nested cyclones; parallel scrubbers, precipitator tubes or ducts; multiple venturis, baghouse filter tubes) can be partially blocked off to maintain high (design) efficiency at reduced volume, with economy of water and power use.

---or, design for maximum possible effluent volume, and "over-clean" at reduced volumes.

GAS DISTRIBUTION[21]

> It will be appreciated that the efficiency of a precipitator is greatest when the velocity of the gas through the cross-section of the electrode system is uniform, and no gas is bypassing the electrode system. This is ensured by the construction of...models...of the precipitator and inlet flue system. The flow conditions in the model are adjusted to give the same Reynolds number as the full-scale plant, allowance being made for scale factors, gas viscosity, and density. The flow pattern in the model is corrected using splitters and baffles, their position being determined by experiment. Such model tests permit requirements to be worked out in advance, and avoid the difficulties in carrying out such work on site on the finished plant.

2. Effect of pressure drop within the gas cleaner on efficiency and capacity of collector---

Electrostatic precipitators will experience negligible change in resistance to flow in operation because of large cross section and control of build-up conditions (temperature and humidity) and regular rapping for dust removal.

Bag filters, when new, have very low resistance and efficiency. Sometimes a pre-coat of dust is applied to make the initial cleaning of process fume more effective, for the buildup of dust increases both efficiency and pressure drop, until the cleaning (by shaking or reverse flow of air) cycle is initiated (often by a pressure signal). Then efficiency will be at a lower (but still effective) level until the dust layer reforms on the fabric.[22] Wet scrubbers increase in efficiency with increased resistance due to mechanical constriction of the throat area or added water input. The proportionality of change as attributed to Semrau's correlation was described earlier.

Cyclone's efficiency also depends upon pressure drop. These are only used with coarser, easily collected dusts, however, and usually with a view to product recovery as much as to gas cleaning. As such, they may usually be regarded as process equipment. The rules relating pressure drop, capacity and efficiency are available in the Air Pollution Engineering Manual.[23]

3. Effect of dust loading---

An electrostatic gas cleaner is in principle a constant efficiency device, so that any change in inlet loading should be reflected proportionally in the outlet stream loading. However, in actuality changes in dust build-up

[21] E. R. Watkins & K. Darby, The Application of Electrostatic Precipitation to the Control of Flume in the Steel Industry. Fume Arrestment, ibid.

[22] M. W. First, L, Silverman, Predicting the Performance of Cleanable Industrial Fabric Filters, Jour. APCA, 13, 12, Dec. 1963, p. 581.

[23] Public Health Service Publication No. 999-AP-40

occur, adversly affecting the propagation of a uniform electric field. Plate spacing must be designed to accommodate the condition of heaviest expected dust loading. Automatic controls are often required to maintain an optimum electric field without spark-over.

A well designed bag filter will be unaffected by a change in inlet loading except that automatic cycling of the bag cleaning system will adjust to the change within its limits of variability.

A wet scrubber will yield constant efficiency for a given pressure drop. Therefore, a change in inlet loading will be reflected proportionately in the outlet loading. However, wet scrubbing systems can be very adaptable to changing conditions, provided sufficient power is applied. A venturi throat can easily be closed to maintain a given effluent level with increased dust generation in the process. A process whose fume output varies widely with time could be matched by cleaner adjustments to maintain a constant acceptable output of fume.

4. Relationship of particulate as generated by different processes to collecting efficiency.

In Appendix C, "Characteristics of Emissions," of the technical counterpart of this report, entitled "A Systems Analysis Study of the Integrated Iron and Steel Industry" (May 15, 1969), some data are presented on the nature of particulate material as generated by various processes and conveyed by gases emitted from the process vicinity. This dust is generally non-uniform from one particle to another and from process to process. The differences may be categorized as particle size, shape, density, and composition.

The mechanisms of particle collection on which gas cleaning equipment are based vary in collecting efficiency generally with particle physical properties. The chemical nature of the dust may affect its susceptibility to electric charging. (This would primarily affect electrostatic precipitation, but could be a second order effect in wet scrubbing and fabric filtration) and interaction with water droplets. (Solubility and chemical activity would affect the water cycling, dust handling, and collector surface maintenance in wet collectors.)

Some general variations in the efficiency of collectors with these particle properties can be drawn. Stairmand[19] has presented grade efficiency curves (typical of industrial collectors in the mid-1950's) for various types of dust collecting equipment. These show the efficiency of collecting particles of a given size. The curves were based on test results using a standard dust (Table III) with a 2.7 specific gravity. These curves can be used to indicate the relative applicability of each type of equipment to different process fumes. As shown in figures 14 to 25, the efficiencies generally are lower (often dropping abruptly) for finer grades of dust. Some devices are more economical to operate but generally do not clean fine particles from gases as well as others.

By making a density correction, the curves can be applied to dusts for which particle size distribution data (as in Table III) are known. Some distribution data is given in the aforementioned Technological Report, Appendix C. No quantitative data are available upon which to base corrections for particle shape, composition, and surface differences, so such an application of the curves will not be quantitatively precise.

Particle size distribution data available for this kind of analysis are inadequate in some measure. The size ranges reported are usually too large and require excessive averaging in the region of greatest variation in efficiency on the grade efficiency curve--the fine particle size region. Steelmaking dust is largely concentrated in this region. Whether or not averaging according to the log-probability distribution would be applicable to distributions having given data ranges such as 0 - 1 micron or 0 - 5 microns is not known.

The shape of the grade efficiency curve may be shaped somewhat by process variables which alter the properties of the dust, by conditioning of the dust by humidity and temperature control in the case of electrostatic precipitation, by collector geometry (affecting treatment time) and energy input. See Table IV. The development of a family of curves should be undertaken, showing grade-efficiency variations at different levels of pertinent operating variables (such as scrubbing energy level or electrostatic precipitation treatment duration). Note that steelmaking fume can generally be adequately removed with a scrubber pressure drop of 40+ inwg., or by electrostatic precipitators whose geometry, control, and energization are specifically selected from that application. Using the given curves, however, to analyze the effect of each type of treatment on actual process dusts will give a comparison of dust property effects on performance of each collector--at least, relative indications may be drawn. Efficiencies measured in the field, of equipment collecting dust from the actual processes, dusts whose properties would also be tested under the collecting conditions, would allow precise comparisons, more precise (and probably more economical) designing, and knowledgeable predictions of performance. Such data is generally not available, not very good (due to difficulties of measuring particle size and dust concentration with accuracy under conditions of collection, or difficulties of correlating standard test results--which, too, are costly and limited--to the conditions of temperature, humidification, agglomeration, dispersion, etc., under which a dust would be collected), or undisclosed (being the proprietary tools of a competitive collector industry). So Stairmand's contribution, while limited, is available and useful for relative comparisons.

Stairmand's fabric filter curve (see Figure 7) is not reproduced here, as it is based on a theoretical calculation for a new filter. A more typical grade efficiency is given by Figure 8[24], based on test results. However, both indicate that the efficiency would not go to zero as particle size approaches zero. This is discussed by Stairmand[2] in terms of a diffusional collecting mechanism which comes into play at an increasing rate as particle size diminishes. The zero drop-off in the other grade efficiency curves represents the failure of the inertial impaction mechanism to collect small particles. Stairmand's discussion includes diffusion of particles to water droplet targets as well as filter media, so this effect should also apply to wet scrubbing. As indicated by the U-shape of curves in Figure 11, the mechanism of diffusion seems also to apply to electrostatic precipitation. This mechanism, then, would suggest an upward alteration of the grade-efficiency curves. (Variations

[24] Whitby, K. T., and Lundgren, D. A., Technical Report Aug. 1961, Fractional Efficiency Characteristics of a Torit Unit Type Cloth Collector, Torit Mfg. Co., St. Paul, Minn.

in this effect will occur with temperature and particle concentration.) By designing low flowrate collectors, and optimizing inlet conditions, one could take advantage of this mechanism with fine dusts.

The investigation of this diffusional mechanism (what it does in present collectors, and its potential for new equipment development), the testing and sampling techniques which contribute to the dirth of data, and filling the data gaps should be undertaken to assist proper design of collectors and prediction of costs.

The grade efficiency data shown is applied in Table V to various process dusts with known particle size distributions. By multiplying each of the size range limits of these distributions by the square root of the ratio

$$\frac{\text{specific gravity of process dust}}{\text{standard dust specific gravity}},$$

the curves can be used to obtain the average efficiency of collection for the weight fraction of dust within those corrected size range limits. By multiplying each such fractional efficiency by the corresponding weight fraction, and summing, the net efficiency for the collector and dust combination is obtained. But, note that it is only a relative indication of efficiency, and is not to be taken absolutely and compared to a measured efficiency from the field. We have found just such comparisons to show calculated precipitator efficiencies low, and calculated wet scrubber efficiencies (using extrapolations to Stairmand's 22 inwg. pressure drop situation) high for open hearth dust and low for BOF dust (using the actual size distributions in each case for calculating efficiencies).

Table III Grading of W.C.3 Test Dust[19] and Sample Efficiency Calculation for Self-Induced Spray Collector (ΔP=6.1 inwg.)

Size Range of Grade, μ	Median Size in Grade, μ	Wt. Fraction in Grade		% Efficiency of Median Size (Fig.23)		Weighted Efficiency
104 - 150	127	.03	x	100	=	3.0
75 - 104	89.5	.07	x	100	=	7.0
60 - 75	67.5	.10	x	100	=	10.0
40 - 60	50.0	.15	x	100	=	15.0
30 - 40	35.0	.10	x	100	=	10.0
20 - 30	25.0	.10	x	99.5	=	9.95
15 - 20	17.5	.07	x	98.5	=	6.90
10 - 15	12.5	.08	x	97.5	=	7.76
7.5- 10	8.75	.04	x	96.5	=	3.86
5 - 7.5	6.25	.06	x	95.0	=	5.7
2.5- 5	3.75	.08	x	90.0	=	7.2
0 - 2.5	1.25	.12	x	63.0	=	7.56
		1.00				93.93 Total Efficiency

Table IV

VARIOUS DEDUSTING SYSTEMS TREATING 60,000 CU.FT./MIN. OF DUSTY GASES AT 68°F

(The grade efficiency curves for each type of collector are shown in figures 14 to 25. [19])

Type of Equipment	Efficiency on standard dust, % (1)	Pressure drop in. w.g.	Water usage, gal./ 1,000 cu. ft.
Medium-efficiency cyclones	65.3	3.7	—
High-efficiency cyclones	84.2	4.9	—
Tubular cyclones	93.8	4.3	—
Irrigated cyclones	91.0	3.9	4.0
Low pressure-drop cellular cyclones	74.2	1.4	—
Electrostatic precipitators	94.1	0.6	—
Irrigated electrostatic precipitators	99.0	0.6	2.5
Frame-type fabric filter	99.9	4.0	—
Reverse-jet fabric filter	99.9	5.0	—
Spray tower	96.3	1.4	18.0
Wet impingement scrubber	97.9	6.1	3.0
Self-induced spray collector	93.5	6.1	0.6
Venturi scrubber	99.7	22.0	7.0
Disintegrator	98.5	—	5.0

(1) See Table III

---

[19] C. J. Stairmand, Design and Performance of Modern Gas-Cleaning Equipment, Jour. Institute of Fuel (Brit.), Feb. 1956, p. 58

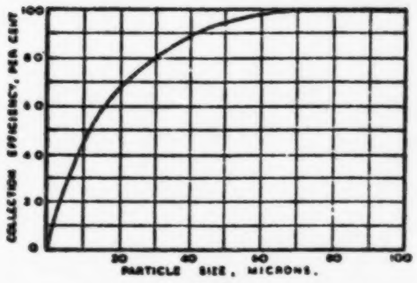


Fig. 14
Medium efficiency, high-throughput cyclone.
Efficiency at 5 microns = 27%.

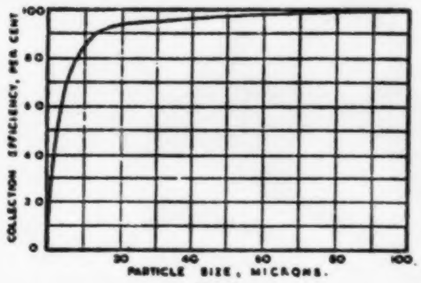


Fig. 15
High efficiency (long cone) cyclone.
Efficiency at 5 microns = 73%.

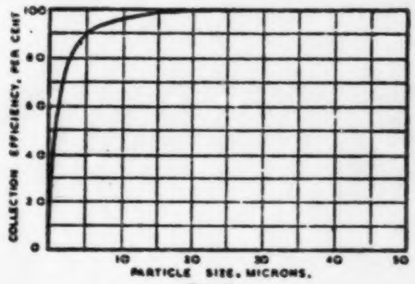


Fig. 16
Small diameter, tubular cyclones.
Efficiency at 5 microns = 89%.

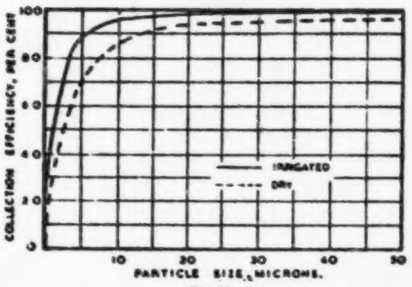


Fig. 17
Large diameter dry and irrigated cyclone.
Efficiency at 5 microns = 87%.

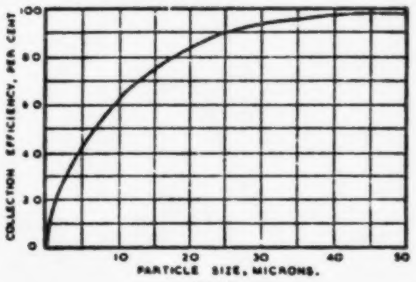


Fig. 18
Low pressure drop cellular cyclone.
Efficiency at 5 microns = 42%.

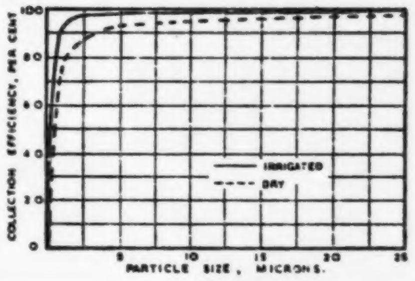


Fig. 19
Electrostatic precipitator. Irrigated—efficiency at 5 microns = 94%
Dry—efficiency at 5 microns = 92%.

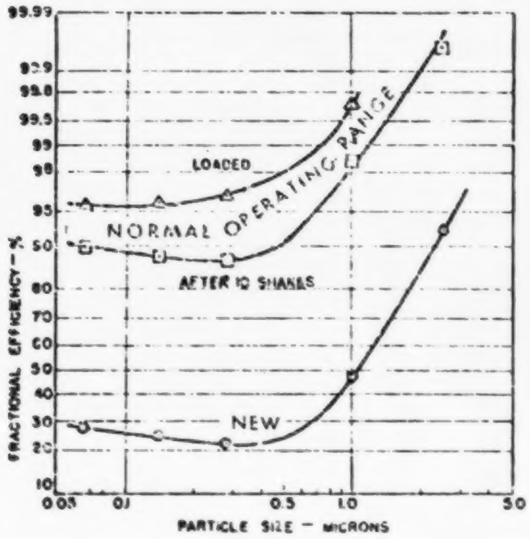


Fig. 8

Fig. 20
Fabric filter (see Figs. 7 and 8)
Efficiency at 5 microns = 99.9%.

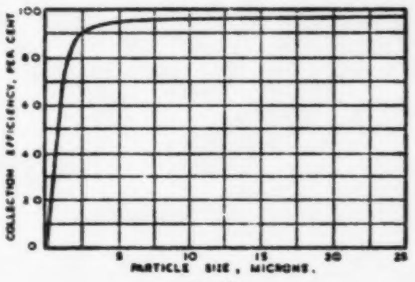


Fig. 21
Spray tower.
Efficiency at 5 microns = 94%.

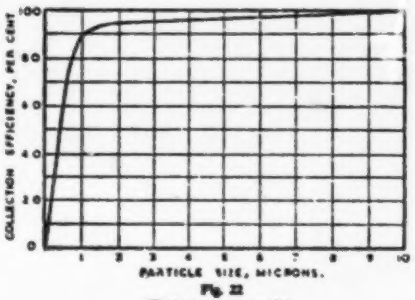


Fig. 22
Wet impingement scrubber.
Efficiency at 5 microns = 97%.

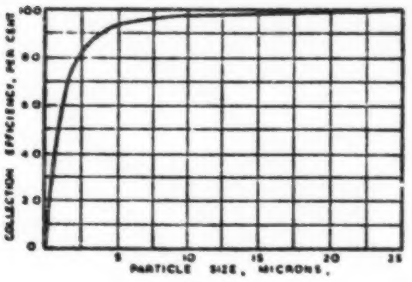


Fig. 23
Self-induced spray collector.
Efficiency at 5 microns = 93%.

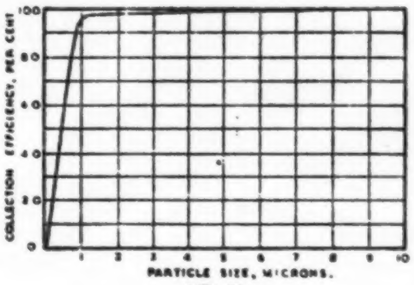


Fig. 24
Venturi scrubber
Efficiency at 5 microns = 99.6%.

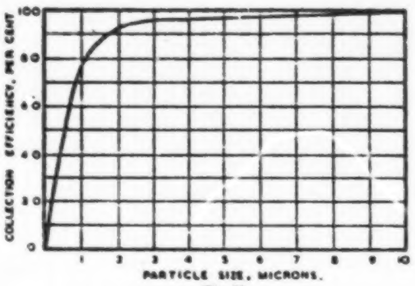


Fig. 25
Disintegrator gas washer.
Efficiency at 5 microns = 98%.

Grade Efficiency Curves for Various Collectors[19]
Typical of Performance Required in the mid-1950's.

Table V

RELATIVE EFFICIENCY OF COLLECTING EQUIPMENT FOR VARIOUS PROCESS DUSTS AND COLLECTORS

	Sinter Strand	Flux Fraction (as in self-fluxing sinter making).	Basic Oxygen Furnace	Open Hearth	Electric Arc Furnace	Pressure Drop (in. water)
Particle Specific Gravity	4.0	2.7	5.0	5.2	3.93	
Inlet Loading, $\frac{\text{grains}}{\text{SCFD}}$	4		4 - 8	2 - 7	3 - 6	
Required Efficiency, % to 0.05 grains/SCFD	98.73		98.9- 99.38	97.5- 99.28	98.33- 99.17	
Predicted Efficiency, %, for:						
Cyclones						
High Throughput	65	59	N.A.	N.A.	N.A.	3.7
High Efficiency	91	90	"	"	"	4.9
Multicyclone	98.5	98	"	"	"	4.3
Wet	97	96	"	"	"	3.9
Wet Scrubber						
Low Energy						
Spray	97	97	N.A.	N.A.	N.A.	1.4
Wet Impingement	99.75	99.52	"	"	"	6.1
Self-Induced	98.25	98	"	"	"	6.1
High Energy						
Disintegrator	99.32	98.95	72	88	86	
Venturi	99.98	99.95	85*	94.5*	94*	22*
Electrostatic Precipitator						
Dry	99.00	95.5	64**	83**	81***	.6
Wet	99.86	98.95			86**	.6
Fabric Filter	99.99	99.99	97.8	99.5	99.5	4.0

* A pressure drop of 40+ inwg. normally is required to clean steelmaking fume to the specified 0.05 grains/DSCF with a venturi scrubber.

** The codes in the mid-1950's when the grade efficiency data were typical in Britain were less restrictive. Precipitator designs today can be guaranteed to 99.5% efficiency if required. But the figures indicate relative collectability.

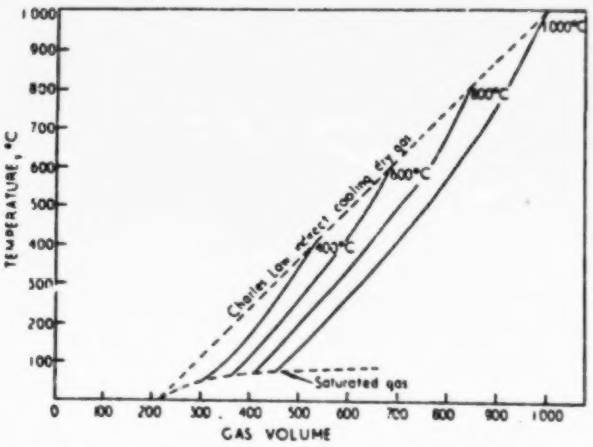
*** With proper humidification,**

5. Effect of temperature---

From the gas laws, volumes vary directly with absolute temperature. This has several implications for the gas cleaning system:

a) The fan power requirement is proportional to volume. So, many systems cool the gases to a minimum practical temperature before entry into the fan unless thermal lift must be maintained to get rid of noxious gases in the effluent. Since positive pressure ordinarily makes for simpler structure in a precipitator, and best efficiency requires several hundred degrees of temperature, this benefit is ordinarily not available for a forced draft precipitator fan. However, in the wet scrubber, where efficiency depends on a high gas stream energy, at a high power consumption level, the cooling of gases is particularly beneficial.

b) Precipitators and especially bag filters are limited in the temperature at which they operate. Thus cooling as a pre-conditioning step is required before entry to the gas cleaner on many processes. The method of cooling also effects the volume of gas to be handled.



Variation of volume with temperature when gases are cooled by the evaporation of water

Fig. 9 [21]

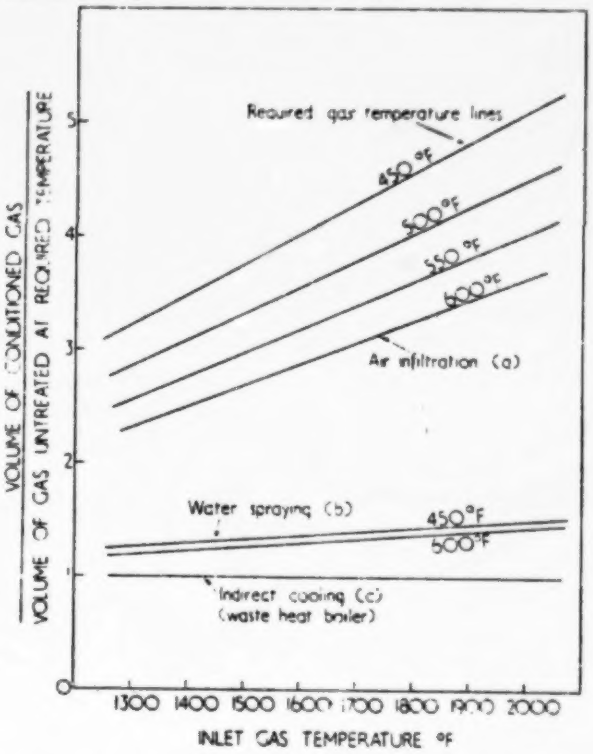


Fig. 10[25] ***Waste gas volume variation for different gas conditioned temperatures by air infiltration and water spraying***

[25] W.P.C. Ungoed & W.F. Needham, Waste Heat Boilers on Open Hearth Furnaces. Fume Arrestment. Special Report 83, British Iron & Steel Institute, Ibid.

[21] E.R. Watkins and K. Darby, The Application of Electrostatic Precipitation to the Control of Fume in the Steel Industry. Fume Arrestment, ibid.

Effect of Humidity.

Water additions to the gas stream or gas cleaner system is a frequently required pre-conditioning step. The humidity of the gas entering a baghouse must be sufficiently below the dew point to preclude corrosion of the structure and clogging of the bags with moist cake. On the other hand, quenching is an economical way to cool, avoiding expensive radiation ducting or excessively large components to handle dilution air.

Humidity is sometimes critical in the electrostatic precipitation of certain dusts of high resistivity. Again, it can be coupled with cooling quench in the pre-conditioning zone, but care must be taken to stay above the dew point temperature. No liquid effluent results from these cases. It should be noted that in both of the above systems, the acid dew point is also critical from a corrosion point of view in those cases where sulfur dioxide is a significant process effluent component, such as the open hearth and some coal burning processes. While it has been noted that sulfur dioxide can be beneficial in the precipitation of some process dusts, this benefit is likely to be lost as sulfur dioxide regulations take effect.

Water flushing of elbows, fan blades, and other parts of the systems has been effectively used to inhibit impingement abrasion and to prevent dust buildup.

Corrosion, abrasion, dust buildup and excessive temperature are the most frequent maintenance problems on a gas cleaning system. Where water is used as a remedy, careful pH control is important, as is solids build up in a recirculating water system.

Except for this preventive maintenance application, water effluents usually are the result of wet scrubbing or wetted surface precipitation. (This later finds application to electric arc furnace fume cleaning where satisfactory particle resistivity for collection is difficult to achieve, and in sinter plant and blast furnace applications where coarse, abrasive dust must be removed).

EFFECT OF ELECTRICAL RESISTIVITY OF DUST FUME[21]

> Much has been written on the subject of the effect of the resistivity of the dust on precipitator efficiency and it is not proposed to go deeply into this aspect of the subject... It can be shown, however, that for dust of a very high resistivity, precipitation efficiency can be seriously reduced (see Fig. 11 and section on particle sizing), and, for resistivities higher than 10^{11}ohm-cm, difficulties are likely to be encountered. There is some divergence of opinion between different investigators on the value of resistivity at which difficulty is likely to be encountered and it is thought that this is due to a number of factors difficult to control, such as the degree of packing of the dust, so that in practice different forms of apparatus can disagree to a considerable extent. At the same time resistivities measured by any one form of apparatus, when used by an experienced operator, can be related to precipitator performance.

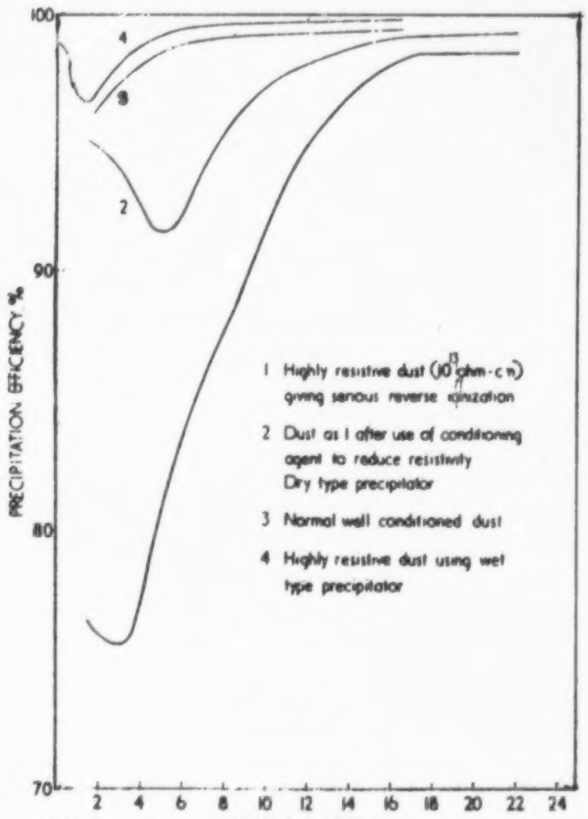


Fig. 11

Variation of precipitation efficiency with particle size

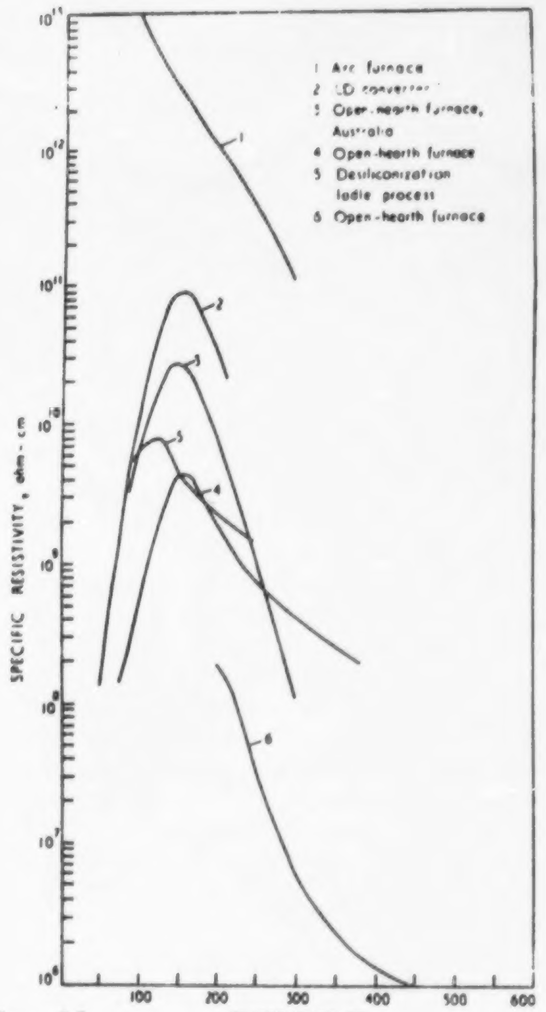


Fig. 12

Electrical resistivity of red oxide fume from various oxygen-blown steelmaking processes

The electrical resistivity of most dusts and fume depends on the nature and condition of the surface of the dust particles, rather than on the material of which the dust is composed; the resistivity is in practice often determined by adsorbed layers of vapor, such as water, sulphuric acid, or ammonia. These usually arise from reactions taking place in the furnace or vessel to which the precipitator is attached; for instance, high-sulphur fuel oil used in firing OH furnaces can produce sulphuric acid, and this in turn is adsorbed by the dust. Where the dust resistivity is high, suitable layers to reduce the resistivity of the dust can be provided by the injection of one of the conditioning agents listed above into the flue before the precipitators. In practice, however, in this country, it has not so far been found necessary to supply any artificial conditioning agent to red oxide dust ..., although difficulties have been reported from abroad. Figure 12 shows the resistivity plotted against temperature for fume originating from LD converters,OH furnaces, arc furnaces, and ladle desiliconization processes.

It will be seen that the resistivity is below 10^{11} ohm-cm in all cases except for fume from the arc furnace. In the case of OH furnaces the dust is normally 'conditioned' by the water vapor and sulphur trioxide resulting from the combustion of the fuel used to fire the furnace.

In the case of the arc furnace, there is normally no such supply of conditioning agent in the gases leaving the furnace as curve 1, which is the resistivity of a dust sample taken immediately at the furnace outlet and is typical of a highly resistive dust without the conditioning surface layer. When a precipitator is attached to an arc furnace, it is necessary, in view of the high temperatures involved, to cool the gases, usually by means of a water spray tower, to an economical level for the precipitator. This has the effect of reducing the gas volume to be treated; and at the same time, the dust is 'conditioned' by water vapor and the resistivity curve assumes the shape shown for the other fume with the peak value below the limit for efficient precipitation.

EFFECT OF PARTICLE SIZE ON PRECIPITATION EFFICIENCY[21]

It can be shown from calculations on the forces acting on charged particles that the efficiency of an electrostatic precipitator should decrease with decreasing particle size; this, however, is not normally borne out in practice and many commercial applications of precipitation are on processes in which much of the fume is submicron, as for instance, blast-furnace gas cleaning and the red oxide fume evolved from oxygen blowing processes.

Figure 11 shows the relationship with precipitation efficiency and particle size for a number of dusts, the first three relating to dry precipitation, and number 4 to a wet precipitator. Curve No. 1 was obtained on a dust whose electrical resistivity was of the order of 10^{13}ohm-cm, and the precipitator was exhibiting signs of severe reverse ionization; it is interesting to note that the fall-off in efficiency becomes increasingly serious for particle sizings below 20 μm. Curve No. 2 was obtained upon the same dust when the resistivity had been decreased by the use of a conditioning agent, while curve No. 3 was obtained on a dust whose resistivity was well below the limit of 10^{11}ohm-cm quoted in the section on resistivity. Curve No. 4, obtained on the wet electrofilter, has a fall-off comparable with the lowest resistivity dry dust (curve No. 3); in this case, although the dust was initially highly resistive, the resistivity of the dust in the precipitator was reduced to a safe level by the cooling and natural conditioning effect of the spray tower preceding the precipitator; in addition, since the particles were deposited on a moving flow of water, the effect of high resistivity would be of no consequence in any case.

Since this fume consisted of non-magnetic particles of spherical form it was possible, using the electron microscope, to continue the grading beyond the limit of most forms of grading apparatus; these gradings indicated that there was no serious fall-off of precipitator efficiency for particle sizings down to the order of .01μm.

While the theory of the motion of the dust particles under the effect of the electric field assumes that the dust is deposited as individual particles, there is in practice a strong tendency for very fine fume to agglomerate into masses consisting of hundreds of fine particles, such agglomerates behaving as single, much larger particles in the electric field, with the result that efficiency is higher than would be theoretically calculated for such a fume. This is normally considered to be one of the explanations why the precipitator fails to obey the basic theory. It is also one of the difficulties of carrying out dust gradings and limits their value, since clearly what is required of a dust grading apparatus is the grading including the effect of agglomeration, and one of the debatable points in dust grading methods is the energy which should be used to disperse the agglomerates formed in the precipitators in a dust grading apparatus. An interesting feature is the action of the conditioning agent, as illustrated by curves 1 and 2, since it would appear that, in addition to reducing the resistivity of the dust, the agglomerating properties are also materially improved. The authors consider that for efficient precipitation it is necessary, particularly in a dry precipitator, for the dust to have the correct agglomerating properties in addition to a suitable electrical resistivity value.

DUST CONCENTRATION AND ELECTRODE DESIGN[21]

In recent years a considerable amount has been written on the subject of high-corona electrodes and their importance in the precipitation of red oxide fume. It is the experience of the authors of this paper that high-emission electrodes can only usefully be applied where suppression of the corona discharge current takes place with the normal type electrode. Its effect in this instance is to bring the current discharge back to what has been found to be a reasonably normal value for efficient precipitation. Corona suppression is caused when the dust concentration is very high and the particle sizing extremely small, the effect being to blanket the corona electrode and to inhibit corona discharge in much the same way that the control grid around the cathode of an electronic valve can be used to limit the current flowing across the valve from anode to cathode. High-corona current electrodes should be confined to the stages of a precipitator where corona suppression is likely to take place and dust concentrations are heavy.

6. Adaptability of particulate removal systems to removal of gaseous pollutants.

Studies on the injection of dry, powdered limestone, dolomite, manganese dioxide, alumina and other metal oxides to process gases containing sulfur dioxide indicate that some 30 - 60% of the SO_2 can be absorbed by the additive and removed in the particulate removal system, as an added inlet loading.

A bag filter could do this effectively. A wet scrubber system gives the added benefit of a liquid absorbtion stage and has yielded good test results. Alkaline solutions may be used without the powder injection.

A catalytic oxidation process unit could be inserted in series following a precipitator so the high temperature at which the precipitator operates could be used in the oxidation. The process scrubbing would preclude following with a baghouse or precipitator.

These systems are in the development phase and their use is contingent on economics and competitive process developments.